The effectiveness of the GEOL336 Iceland virtual fieldtrip to aid student sketching and interpretation of lava flows

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Frontispiece

"Learn by doing"

- Central School Motto

Abstract

Fieldtrips are a critical component of learning in the geosciences to develop skills, integrate knowledge, foster geoscientific identities and motivate student engagement. Given the development of new technologies and the growing demand for more inclusive classroom environments, virtual fieldtrips are increasingly being considered as an effective form of teaching to either augment or replace fieldtrips. However, little research has established the effectiveness of virtual fieldtrips at aiding the development of geological skills (e.g., sketching and interpretation), and the learning gains measured as a result of virtual fieldtrips. The GEOL336 Iceland virtual fieldtrip was developed to teach a third-year undergraduate volcanology course (GEOL336: Magmatic Systems and Volcanology), at the University of Canterbury, about volcanic features and processes at three field locations in Iceland (e.g., Reykjanes, Heimaey and Krafla). The virtual fieldtrip was designed to aid the development of geological skills (e.g., sketching and interpretation), which are normally taught and learned on fieldtrips. The effectiveness of the virtual fieldtrip to aid student sketching and interpretation was measured by calculating the learning gains for an in-class exercise, which was completed by students pre- and post- the virtual fieldtrip. The in-class exercise required students to sketch and interpret a photograph of a lava flow from Sumner Beach near Christchurch, New Zealand. Following the virtual fieldtrip, a reflective questionnaire provided students an opportunity to reflect on their learning in the virtual fieldtrip and provided qualitative data for this research. Positive learning gains were calculated for the sketching, annotation and interpretation parts of the in-class exercise. The virtual fieldtrip was most successful at aiding student interpretation based on the higher learning gains for the interpretation parts of the in-class exercise. Possible reasons for these higher learning gains included the three-dimensional visualisations and instructional videos implemented in the virtual fieldtrip, which allowed students to spatially explore the volcanic features and processes; the reinforcement of GEOL336 content in the virtual fieldtrip; and an increase in student motivation, interest and engagement as a result of the virtual fieldtrip. Based on the in-class exercise and reflective questionnaire results, a framework was developed for tertiary geology virtual fieldtrips. This framework includes constructively aligning virtual fieldtrip content, providing a range of assessment opportunities, implementing appropriate technologies to deliver

virtual fieldtrip information, providing opportunities for student reflection, connecting students to the virtual fieldtrip experience, and designing a learning space which encourages group discussion.

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Chapter 1

Introduction

1.1 Context of Study

Field education is a crucial component of geology courses for learning and developing skills; integrating concepts (e.g., Boyle et al., 2007; Lonergan and Andresen, 1988; Petcovic, Stokes, and Caulkins, 2014; Pyle, 2009); providing transformative experiences that provide scientific identity for students in these fields (Kastens, Agrawal, and Liben, 2009; Mogk and Goodwin, 2012; Petcovic et al., 2014; Pyle, 2009); and developing visual-spatial skills important for geologists (Kastens and Ishikawa, 2006). Furthermore, some evidence suggests that through engaging in fieldwork students learn more effectively about the earth (Elkins and Elkins, 2007).

However, field education is becoming increasingly more difficult to implement due to concerns about time, logistics, finance and safety pressures (e.g., Boyle et al., 2007; Boyle, Ryan, and Stokes, 2009; Feig, 2010; Jolley et al., 2018; Petcovic et al., 2014). Virtual fieldtrips have become an increasingly popular alternative to fieldtrips to overcome these challenges, while also utilising the recent advances in technology (such as the development of high quality computer-based learning environments) and the increase in broadband access (Mead et al., 2019).

The development of virtual fieldtrips involves collecting, compiling and processing visual data from a location of interest to either augment or replace fieldwork (Dolphin, Dutchak, Karchewski, and Cooper, 2019). Virtual fieldtrips have been developed as an educational tool for tertiary learning in geology courses to augment traditional fieldwork (Arrowsmith, Counihan, and McGreevy, 2005), enhance basic mapping skills (Houghton, Lloyd, Robinson, Gordon, and Morgan, 2015) and develop strategies for approaching fieldwork (Dolphin et al., 2019). Thus, virtual fieldtrips can provide a way to complement or provide an effective alternative to traditional fieldwork practices. However, little is known about the learning which takes place as a result of these experiences (Mead et al., 2019).

The GEOL336 Iceland virtual fieldtrip was implemented in GEOL336 (an undergraduate magmatic systems and volcanology course at the University of Canterbury) to teach students about physical volcanological processes at three locations in Iceland (Reykjanes, Heimaey and Krafla), and to aid the development of geological skills such as sketching and interpretation. Three-dimensional (3D) visualisations and instructional videos were implemented in the virtual fieldtrip to allow students to spatially explore the landscape.

The primary aim of this research was to assess the effectiveness of the GEOL336 Iceland virtual fieldtrip to aid student sketching and interpretation of lava flows. This was tested by measuring student learning within an in-class exercise that was completed pre- and post- the GEOL336 Iceland virtual fieldtrip. The in-class exercise assessed student sketching and interpretation of a photograph of a lava flow near Sumner Beach in Christchurch, New Zealand. A reflective questionnaire was completed by students following the virtual fieldtrip to allow students to reflect upon their learning and provide feedback.

1.2 Literature Review

1.2.1 Geological Fieldwork

Fieldwork is valued in geology for its broad development of knowledge, skills, and scientific and professional identities (e.g., Boyle et al., 2007; Feig, 2010; Kastens et al., 2009; Petcovic et al., 2014; Whitmeyer et al., 2009). Skills developed in geology are understood to be best acquired through active learning strategies where they can be learned and practiced through authentic learning activities. Therefore, authentic activities are needed where specific skills can be learned and practiced (Lonergan and Andresen, 1988). These skills are most commonly taught through authentic enquiry and exploration teaching methods in fieldwork (Elkins and Elkins, 2007; Gonzales and Semken, 2006).

Observing, measuring and recording data from outcrops are regarded as part of the primary skills that a field geologist should have (Nicholas, 2000). Other skills often associated with geological fieldwork are listed below (Dolphin et al., 2019; National Research Council, 2006, p. 195):

- enhancing mastery of subject matter
- developing scientific reasoning
- understanding the complexity and ambiguity of empirical work
- developing practical skills
- cultivating interest in science and in learning science
- developing teamwork abilities

According to most geologists, fieldwork is an indispensable part of teaching and learning in geology courses (Petcovic et al., 2014). Mogk and Goodwin (2012) claim that field education has at least five important benefits: 1) field education yields improvements in student knowledge and problem-solving skills; 2) it enhances student ability to reflect upon their own thinking; 3) it generates positive feelings that lead to enhanced learning; 4) it offers direct and immersive experiences of geologic phenomena; and 5) it introduces students to professional practice. Furthermore, field based learning is valued as authentic preparation for careers in geology (de Wet, Manduca, Wobus, and Bettision-Varga, 2009; Perry, 2004).

Although field education yields numerous benefits, the field environment can present significant learning challenges to geology students. This is because the field environment is composed of 'novel' cognitive, psychological, social and geographic variables (Dohaney, Brogt, and Kennedy, 2015; Orion and Hofstein, 1994), which makes instruction and acquisition of effective skills more challenging. Challenges include creating an experience that maximises achievement of course intended learning outcomes, finding time to spend in the field and transporting students into the field (Dolphin et al., 2019). Further problems can include reduced departmental funding and increased student numbers (Bradbeer, 1996). Any one or combination of these factors may result in an educational experience that is either not accessible to all students, or would have suboptimal learning outcomes (Hall, Healey, and Harrison, 2004).

1.2.2 Virtual Fieldtrips

Virtual fieldtrips have been used widely within geology education for a variety of topics, skills and education levels (Arrowsmith et al., 2005; Dolphin et al., 2019; Houghton et al., 2015; Mead et al., 2019; Stainfield, Fisher, Ford, and Solem, 2000). The concept of providing field-based learning opportunities through virtual fieldtrips is not new (Stainfield et al., 2000); however, it has only recently become possible to deliver on the promise of that idea (Mead et al., 2019). Virtual fieldtrips can include various types of media such as 3D visualisations, imagery and videos (Mead et al., 2019). The complexity of virtual fieldtrips vary, from those that provide pictures and text to offer descriptions of an area, to those that are immersive experiences that provide an interactive problem-based approach (e.g., Atchison and Feig, 2011).

Virtual fieldtrips offer many advantages to enhance teaching and learning within geology courses. Students have more autonomy over their own time as there are fewer time constraints than in the field (Dolphin et al., 2019). This allows students to work at their own pace (Arrowsmith et al., 2005; Fletcher, France, Moore, and Robinson, 2002) and revisit locations within the virtual fieldtrip (Hurst, 1998). Virtual fieldtrips also mitigate logistical barriers such as poor weather conditions and transportation issues (Dolphin et al., 2019), while also avoiding the financial burden of fieldwork to departmental budgets (Jacobson, Militello, and Baveye, 2009; Litherland and Stott, 2012).

Increasingly, educators are becoming aware of creating a more inclusive field environment (Carabajal, Marshall, and Atchison, 2017). Fieldwork can pose obstacles to students with mobility constraints (Stainfield et al., 2000). These physical barriers in the field may no longer present impediments, as virtual fieldtrips can address this constraint for those who would otherwise have trouble navigating it (Arrowsmith et al., 2005). Virtual fieldtrip activities in a predictable classroom location can mitigate the anxiety issues that some students feel about fieldwork (Boyle et al., 2007).

Virtual fieldtrips can also utilise 3D visualisations (Hurst, 1998). Virtual fieldtrips can present images from a variety of viewpoints (aerial view, cross-sectional view and animated rotating block diagrams) at many different scales, so relationships that are difficult to view through two-dimensional (2D) field cross-sections or photos can be better visualised in 3D (Hurst, 1998).

Although virtual fieldtrips have many advantages, there are some limitations. One limitation of virtual fieldtrips is that participants do not have the opportunity to interact with peers in a flexible manner (Hurst, 1998); therefore, virtual fieldtrip activities cannot reproduce the social interactions that would occur in the field (Çaliskan, 2011; Stumpf, Douglass, and Dorn, 2008). For example, natural language and gestures have not yet been incorporated in virtual fieldtrips. Therefore, the answers to questions must be pre-prepared and there must be a clear method to be able to finish the virtual fieldtrip (Hurst, 1998).

Another major disadvantage is that a virtual fieldtrip is only an abstraction of the real thing. This means that virtual fieldtrips struggle to communicate the feeling of a spectacular geological landscape. Virtual fieldtrips do not have the physical impacts of fieldwork, which include being able to touch and smell while working in the field location (Hurst, 1998; Stainfield et al., 2000). Several studies have concluded that virtual learning greatly improves field experiences when used to prepare for field trips, but should not replace fieldwork (Orion and Hofstein, 1994; Stainfield et al., 2000).

Measuring the Effectiveness of Virtual Fieldtrips

Virtual fieldtrips have many benefits and some limitations; however, little is known about the learning which takes place as a result of these experiences (Mead et al., 2019). Pre- and post-test design has been utilised in some studies to measure the effectiveness of virtual fieldtrips (Mead et al., 2019; Stumpf et al., 2008; Turney, Robinson, Lee, and Soutar, 2009; Whitelock and Jelfs, 2005). These studies have found virtual fieldtrips to be as effective as fieldtrips at improving student learning and effective at engaging students. Stumpf et al. (2008) found knowledge gains in virtual fieldtrips are similar to traditional fieldwork; whereas, some studies have reported that virtual fieldtrips did not develop student understanding better than traditional fieldwork (Dolphin et al., 2019). In other studies, students showed statistically significant gains in content knowledge (Mead et al., 2019). This is promising as it suggests that virtual fieldtrips have similar learning outcomes to real fieldtrips. Assessment of students who engaged with the virtual fieldtrips revealed an increase in their understanding about how scientists can come to different conclusions from the same data (Mead et al., 2019).

In Dolphin et al. (2019), the effectiveness of a virtual fieldtrip was assessed using participant observations and instructor perceptions. This showed how the students approached the tasks. Student feedback, teacher feedback and questionnaires have also been used to test the effectiveness of virtual fieldtrips (Arrowsmith et al., 2005; Dolphin et al., 2019; Mead et al., 2019). Increased participation in classroom learning (Litherland and Stott, 2012), self-reported student learning (Clary and Wandersee, 2010) and student engagement due to the novelty structure of virtual fieldtrips (Dolphin et al., 2019) have been shown in the literature.

1.3 Framework for this Research

GEOL336 does not offer any fieldtrips to develop the geological skills usually associated with fieldwork due to limited time and accessibility problems. In previous years, the course instructor identified that students struggled to record observations of lava flows, discuss physical volcanological processes with relevance to magma properties and interpret the geological history of lava flows. Lava flows are outpourings of molten rock, which have a range of compositions, volumes and scales (Kilburn, 2000). They are complex 3D structures that can contain a variety of rock properties due to a breadth of volcanic processes and different cooling histories.

The GEOL336 Iceland virtual fieldtrip was developed to teach students the skills often associated with fieldwork to aid student sketching and interpretation of lava flows. Students were taught about volcanic features and processes within the instructional videos in the virtual fieldtrip. They then participated in a range of exercises, which required them to observe, measure and interpret data from multiple lava flows. These lava flows were displayed in a variety of 3D visualisations, instructional videos and images within the virtual fieldtrip. The lava flows could be manipulated in the instructional videos and 3D visualisations so that they could be observed from a range of perspectives (e.g., side-view and map-view). While completing the virtual fieldtrip, students were also expected to interact with their peers in the classroom, developing transferable skills such as teamwork and communication skills.

This research was designed to assess the effectiveness of the GEOL336 Iceland virtual fieldtrip to aid student sketching and interpretation of lava flows, measure the learning which occurs as a result of virtual fieldtrips and provide a framework to develop successful tertiary virtual fieldtrips for geology courses. However, this research does not compare the effectiveness of the GEOL336 Iceland virtual fieldtrip to aid sketching and interpretation of lava flows with other teaching methods such as traditional laboratory, lecture or fieldwork methods.

1.4 Aims and Objectives

The overall aim of this research was to assess the effectiveness of the GEOL336 Iceland virtual fieldtrip to aid sketching and interpretation of lava flows. This was achieved through the following objectives:

- To review the literature on geological fieldwork and virtual fieldtrips to provide a framework for this research.
- To design the exercises and associated feedback used within the GEOL336 Iceland virtual fieldtrip.
- To design the in-class exercise and reflective questionnaire for GEOL336.
- To analyse the in-class exercise and reflective questionnaire results to determine the effectiveness of the GEOL336 Iceland virtual fieldtrip to aid sketching and interpretation of lava flows.
- To discuss the results, provide recommendations for future iterations of the GEOL336 Iceland virtual fieldtrip and provide a framework for developing tertiary-level geology virtual fieldtrips.

1.5 Thesis Structure

- **Chapter 1** - establishes the context for this research, based on the relevant educational theory informing geological fieldwork and virtual fieldtrips. Chapter 1 provides the framework for the development of the GEOL336 Iceland virtual fieldtrip to be used as an educational tool to aid sketching and interpretation of lava flows.
- **Chapter 2** - addresses the exercise design and associated feedback used in the GEOL336 Iceland virtual fieldtrip. Chapter 2 also establishes the technology used to deliver the content throughout the GEOL336 Iceland virtual fieldtrip.
- **Chapter 3** - addresses the design of the in-class exercise and reflective questionnaire. It presents the development of the in-class exercise based on the relevant geological sketching and interpretation literature. It also presents the design of the associated in-class exercise marking rubric. Chapter 3 also provides some background on reflection in geology and presents the development of the reflective questionnaire.
- **Chapter 4** - presents the results of the in-class exercises and the reflective questionnaires, and combines the quantitative results produced from the in-class exercise with the qualitative results produced from the reflective questionnaire.
- **Chapter 5** - analyses the results of the in-class exercises and the reflective questionnaires to discuss the overall effectiveness of the GEOL336 Iceland virtual

fieldtrip to aid sketching and interpretation of lava flows. It also discusses the limitations of this research.

- **Chapter 6** - provides recommendations based on the results to improve future iterations of the GEOL336 Iceland virtual fieldtrip, and presents a framework for tertiary-level virtual fieldtrips in geology.
- **Chapter 7** - presents the conclusions of this research.

Chapter 2

The GEOL336 Iceland Virtual Fieldtrip

Chapter 2 provides context for the GEOL336 Iceland virtual fieldtrip being developed and implemented within GEOL336. This chapter explains the design and development of the exercises and associated feedback used in the virtual fieldtrip with regards to the relevant educational literature. It also addressing the technology used to deliver educational content in the virtual fieldtrip.

2.1 Context for the GEOL336 Iceland Virtual Fieldtrip

The Krafla Magma Testbed (KMT) is a project which aims to drill into the magma beneath the Krafla volcano in Iceland. The KMT aims to establish the first magma observatory – an international, open access, scientific platform to improve knowledge of magma, geothermal energy and volcano monitoring. The GEOL336 Iceland virtual fieldtrip was developed as outreach for the KMT project.

The GEOL336 Iceland virtual fieldtrip was run by LEARNZ, powered by CORE. LEARNZ is a programme of free online virtual field trips for teachers and their classes, taking them to remote places. CORE Education is a professional learning and development consultancy organisation, which offer a suite of innovative, empowering, and transformational education services. The GEOL336 Iceland virtual fieldtrip was supported by EQC (the Earthquake Commission) and MBIE (Ministry of Business, Innovation and Employment). The GEOL336 Iceland virtual fieldtrip will be referred to as the ’virtual fieldtrip’ for the remainder of this thesis.

2.2 Research Setting

The virtual fieldtrip was implemented in GEOL336 (a third-year undergraduate course at the University of Canterbury, which specialises in magmatic systems and volcanology). GEOL336 teaches student to examine and interpret the nature and origin of igneous rocks and mineral assemblages, as well as the magmatic processes that have produced these materials. GEOL336 is split into multiple topics taught within both the lecture hall and laboratory (Table 2.1). The GEOL336 lava flow module lectures included volcanoes introduction, and lava (Table 2.1). The GEOL336 lava flow module laboratory was the fudge lab (Table 2.1). GEOL336 is a popular third year option; however, it is not a required paper to graduate with a geology major at the University of Canterbury. The pre-requisites for GEOL336 include GEOL242 (a second-year undergraduate geology paper on rocks, minerals and ores) and one additional second-year undergraduate course.

In 2018, fifty-three students were enrolled in GEOL336. Of the fifty-three students enrolled, forty-nine students agreed to participate in this research study.

GEOL336 was targeted to implement the virtual fieldtrip because it has a strong history of educational transformation (Kennedy et al., 2013), a teaching team with interests in geology education and content which is well-aligned with the achievement standards relating to volcanology. The virtual fieldtrip offered an exciting and novel opportunity to virtually take undergraduate students on a fieldtrip to Iceland to experience volcanic landscapes and teach them about physical volcanological processes.

2.3 Locations in the Virtual Fieldtrip

The virtual fieldtrip explored three volcanic locations in Iceland (Reykjanes, Heimaey and Krafla), with each location representing a distinct eruption style. The Reykjanes location focused on pahoehoe lava flows and their associated structures and processes. The Heimaey location focused on a'a' lava flows, their associated structures and processes, and the impacts the associated hazards have on society. The Krafla location focused on volcanic structures and processes that occur at the surface within caldera systems, the models of the magma chamber at Krafla, and the possibilities to use Krafla for geothermal energy extraction.

Week	Lecture Topics		Laboratory
	Lecture One	**Lecture Two**	
1	Introduction	Magma chemistry	M&M magma chamber
2	Isotopes in magma	Mid-Ocean ridge systems	M&M magma chamber and geochemistry
3	Volcanoes introduction	Lava	Fudge lab (first in-class exercise)
4	Volatile content and its influence on eruption style	Explosive magmatism	Airfall
5	Pyroclastic flows	Mass flows	Ignimbrites
6	TVZ	Ballistics	Explosion
7	Phase diagrams	Phase diagrams	Lyttelton petrology and geochemistry
8	Magma diversification	Island arc systems and granitoids	Granites
9	Continental arc systems	Continental alkaline volcanism	Practice lab exam
10	Oceanic intraplate volcanism & flood basalts	Iceland geochemistry	Final lab exam
11	GEOL336 Iceland VFT (Reykjanes)	GEOL336 Iceland VFT (Heimaey)	GEOL336 Iceland VFT (second in-class exercise)
12	GEOL336 Iceland VFT (Krafla)	GEOL336 Iceland VFT (Krafla)	Magma drillers + reflective questionnaire

TABLE 2.1: Topics covered within GEOL336 lectures and laboratories

2.4 Intended Learning Outcomes for the Virtual Fieldtrip

Learning outcomes are useful to both the student and the instructor (Simon and Taylor, 1996). This is because it makes the curriculum design centred on the student. The intended learning outcomes should focus on the curriculum objectives, then make clear what levels of understanding is required by students (Biggs, 2003). Virtual fieldtrip assessment should reflect the nature of the student's experiences, and examine whether the students have attained the intended learning outcomes and performance expectations set forth by the teacher (Klemm and Tuthill, 2003).

In constructive alignment, the teaching and assessment aligns with the pre-determined learning outcomes intended for students to learn (Biggs, 1996). The intended learning outcomes for each location within the virtual fieldtrip were set by the course instructor based on the relevant volcanological features and processes found at each location in Iceland (e.g., pahoehoe lava flows at the Reykjanes location). The teaching tools and assessment used within the virtual fieldtrip were constructively aligned to achieve these intended learning outcomes.

The intended learning outcomes for each location within the virtual fieldtrip (e.g., Reykjanes, Heimaey and Krafla) were aligned with the pre-determined intended learning outcomes for GEOL336, to ensure the teaching and assessment in the virtual fieldtrip were relevant to the course. The intended learning outcomes for GEOL336 are as follows:

- Realise the importance of igneous rocks in geology and to society.
- Identify and classify igneous rocks and their geological environments.
- Use geochemistry to explain why magma is generated, diversifies and erupts.
- Use geochemical data, thin sections, and maps to reconstruct the magmatic and volcanological histories.
- Discuss physical volcanological processes with relevance to magma properties.

The intended learning outcomes for each location with the associated GEOL336 intended learning outcomes can be observed in Tables 2.2 - 2.4.

Reykjanes Intended Learning Outcomes	**GEOL336 Intended Learning Outcomes**	**Reykjanes Questions**	**Bloom's Taxonomy Level for Reykjanes Questions**
- Locate Reykjanes in the context of the fissure-fed volcanism and rifting tectonism of spreading ridges.	- NA	- Can you find the Reykjanes fissure zone on the map?	- Knowledge
- Record systematic and detailed observations of an outcrop and a rock of a typical fissure fed eruption of a pahoehoe flow.	- Discuss physical volcanological processes with relevance to magma properties. - Identify and classify igneous rocks and their geological environments	- What is the average thickness of each of the pahoehoe sheets? - Estimate the number of pahoehoe lava sheets in the outcrop above.	- Knowledge - Comprehension
- Record detailed observations of the map-scale geology and geomorphology of a fissure-fed eruption (etc. toes).	- Discuss physical volcanological processes with relevance to magma properties.	- Use the 3D viewer below to explore different features, then select the descriptions for features.	- Knowledge
- Explain outcrop observations that allow you to identify submarine versus subaerial basaltic volcanism.	- Discuss physical volcanological processes with relevance to magma properties. - Identify and classify igneous rocks and their geological environments	- What is not characteristic of subaqueous eruptions?	- Comprehension
- Combine your observations with the eruption history to explain the typical morphology of an pahoehoe flow.	- Discuss physical volcanological processes with relevance to magma properties.	- What are the structures and textures that are characteristic from front view, side view and map view of a pahoehoe lava flow?	- Comprehension

TABLE 2.2: The Reykjanes intended learning outcomes aligned with the GEOL336 intended learning outcomes. The Reykjanes questions are categoried based on Bloom's taxonomy level

Heimaey Intended Learning Outcomes	GEOL336 Intended Learning Outcomes	Heimaey Questions	Bloom's Taxonomy Level for Heimaey Questions
- Locate Heimaey in the context of the volcanism and tectonism of Iceland.	- NA	- Can you find Heimaey on the map?	- Knowledge
- Record systematic and detailed observations of an outcrop, rock of a typical cone fed a'a' flow.	- Discuss physical volcanological processes with relevance to magma properties. - Identify and classify igneous rocks and their geological environments	- Which of the following best describes a cinder cone? - What is the typical thickness, height and width of an a'a' lava flow	- Knowledge - Comprehension
- Record detailed observations of the map-scale geology and geomorphology of a cinder cone volcano.	- Discuss physical volcanological processes with relevance to magma properties.	- What are cinder cones made of? - Describe the process that creates the cinder-cone fed a'a' lava flows.	- Knowledge - Comprehension
- Record your observations with the eruption history to explain the typical behaviour of an a'a' flow (and the formation of spiky protrusions).	- Discuss physical volcanological processes with relevance to magma properties. - Identify and classify igneous rocks and their geological environments	- What is a typical thickness, width, and length of an a'a' flow? - What causes the >1m spiky protrusions on the surface of an a'a' lava flow?	- Knowledge - Comprehension

TABLE 2.3: The Heimaey intended learning outcomes aligned with the GEOL336 intended learning outcomes. The Heimaey questions are categoried based on Bloom's taxonomy level

Krafla Intended Learning Outcomes	GEOL336 Intended Learning Outcomes	Krafla Questions	Bloom's Taxonomy Level for Krafla Questions
- Record systematic and detailed observations of an outcrop, rock and thin section of a typical obsidian flow and fine-grained rhyolite at Krafla caldera.	- Use geochemical data, thin sections, and maps to reconstruct the magmatic and volcanological histories. - Discuss physical volcanological processes with relevance to magma properties. - Identify and classify igneous rocks and their geological environments	- Make observations of structural features to inform the orientation of the rhyolite (main rock type in image). - What textural features can you see in the rock above?	- Knowledge - Comprehension
- Record and compare systematic and detailed observations of the map-scale geology and geomorphology of tuff cones and caldera volcanoes.	- Discuss physical volcanological processes with relevance to magma properties.	- Use the 3D viewer below to explore distinctive features, then select the descriptions for features.	- Knowledge - Comprehension
- Integrate your knowledge on intrusions in caldera settings to judge conceptual models of the magma beneath Krafla.	- NA	- Which of the following statements best describes shallow intrusions at Krafla from borehole geology? - What are the possible models at Krafla?	- Synthesis
- Compare the implications of different geophysical datasets to illustrate the uncertainty associated with the magma chamber size and shape.	- NA	- What geological techniques are most useful when studying magma bodies?	- Evaluation
- Debate the potential eruptions scenarios and the implications for Krafla geothermal power plant and Iceland as a whole.	- Realize the importance of igneous rocks in geology and to society.	- Summarise the benefits that drilling into a magma chamber may provide to society.	- Evaluation

TABLE 2.4: The Krafla intended learning outcomes aligned with the GEOL336 intended learning outcomes. The Krafla questions are categoried based on Bloom's taxonomy level

2.5 Exercise Development for the Virtual Fieldtrip

Bloom's taxonomy of the cognitive domain categorises what students are being asked "to do" into various levels of learning (Bloom, 1956; Lord and Baviskar, 2007). Curricula may contain a range of lower-level recall-style skills typical of novices, and "applied" complex skills (higher-level skills) typical of experts. The common learning goal verbs (i.e., objective verbs) addressed in geology are identified in Table 2.5.

The lowest three levels of Bloom's taxonomy include knowledge, comprehension and application (Bloom, 1956). Knowledge questions indicate whether a student knows and can recall specific information. Comprehension questions report information or observations. A basic level of knowledge is required to understand comprehension questions. Application questions apply principles to new situations and use known procedures to solves problems (McConnell et al., 2017).

The higher three levels of Bloom's taxonomy include analysis, synthesis and evaluation (Bloom, 1956). Analysis requires students to break information and then organise information into component parts and to find links between data and come up with interpretations. Synthesis questions may ask students to predict an outcome for an event or create multiple hypotheses to explain a phenomenon. Evaluation questions might ask students to appraise, criticise, justify or support an idea or concept (McConnell et al., 2017).

In order to complete the locations within the virtual fieldtrip students needed to participate in a range of activities. The activities within the virtual fieldtrip were developed to focus on both lower-level learning and higher-level learning (Table 2.5). The lower-level questions within the virtual fieldtrip asked students to recall knowledge; make observations from the instructional videos, pictures and 3D visualisations; and apply this knowledge to new situations. The higher-level questions required students to categorise concepts; come up with geological interpretations; and create hypotheses to explain an outcome and justify their answers.

Some studies have identified that the cognitive demands of virtual learning environments can be too complex for learners (Hedberg, Harper, and Brown, 1993; Land, 2000). Cognitive load theory is based on the hypothesis that for effective learning to take place, a person's short-term memory can only process a certain number of elements simultaneously (Chandler and Sweller, 1991; Sweller, 1994). The demands in virtual learning environments include keeping track of the concepts covered; the integration of new and prior knowledge; and the generation and refinement of questions and understanding based on new information (meta-cognitive knowledge dilemma)

(Lim, Nonis, and Hedberg, 2006). These demands were mitigated in the virtual fieldtrip by providing a range of guiding exercises and feedback. The guiding exercises and associated feedback were designed to scaffold students from a lower-level of learning to a higher level of learning. Scaffolding can comprise of supportive learning prompts which can be used to guide the learning process (Dohaney, 2013). This scaffolding directed student attention to the key concepts and the visual cues utilised within the virtual fieldtrip (e.g., Figure 2.3). This can facilitate student meta-cognitive skills, promote knowledge integration and can help guide students to elaborate on their thinking (Land, 2000).

	Bloom's Taxonomy Levels	Objective Verbs	Example Questions from the GEOL336 Iceland Virtual Fieldtrip	
Low-Level	- Knowledge	- Define, identify, label, list, locate, match, name, outline, record, reproduce, select and state.	- Describe the process that creates the cinder-cone fed a'a' lava flows.	Novice
	- Comprehension	- Defend, describe, discuss, estimate, explain, extend, generalise, infer, paraphrase, predict, rewrite and summarise.	- Locate Reykjanes on the map.	
	- Application	- Change, compute, demonstrate, discover, modify, operate, predict, prepare, produce, relate, show, solve and use.	- Make observations and record textural characteristics. - Sketch what a magma chamber under Krafla looks like.	
	- Analysis	- Breakdown, diagram, differentiate, discriminate, identify, illustrate, infer, outline, point out, relate, select, separate and subdivide.	- Compare and contrast the Eldfell and Meeva eruptive sequence. - Provide feedback on the interpretative sketch.	
	- Synthesis	- Categorise, combine, compile, create, devise, design, generate, integrate, modify, organise, plan, rearrange and reorganise.	- Rearrange the following statements into the correct time order	
High-Level	- Evaluation	- Appraise, compare, conclude, contrast, criticise, debate, justify, interpret, relate, recommend, summarise, support, weigh.	- Evaluate the plausibility of converting all of NZ to this form of energy extraction. - Estimate the proportions of the different facies in this photograph.	Expert

TABLE 2.5: Bloom's taxonomy learning stages (in its original form) illustrating the common learning goal verbs that are addressed in geology. All levels of Bloom's cognitive learning stages were addressed in the virtual fieldtrip.

2.6 Exercises within the Virtual Fieldtrip

2.6.1 Interactive Exercises

The interactive exercises in the virtual fieldtrip asked students to locate on a map where in Iceland their 'virtual fieldwork' was taking place. These interactive exercises were conducted at the start of each location. The interactive exercises required students to click on the map, which integrated the geology of the area with the geography of the country using Google Maps. Every map had both a tectonic and geological map overlay that could be turned on to help students locate and familiarise themselves in the geological context of Iceland. An example of an interactive exercise can be observed in Figure 2.1.

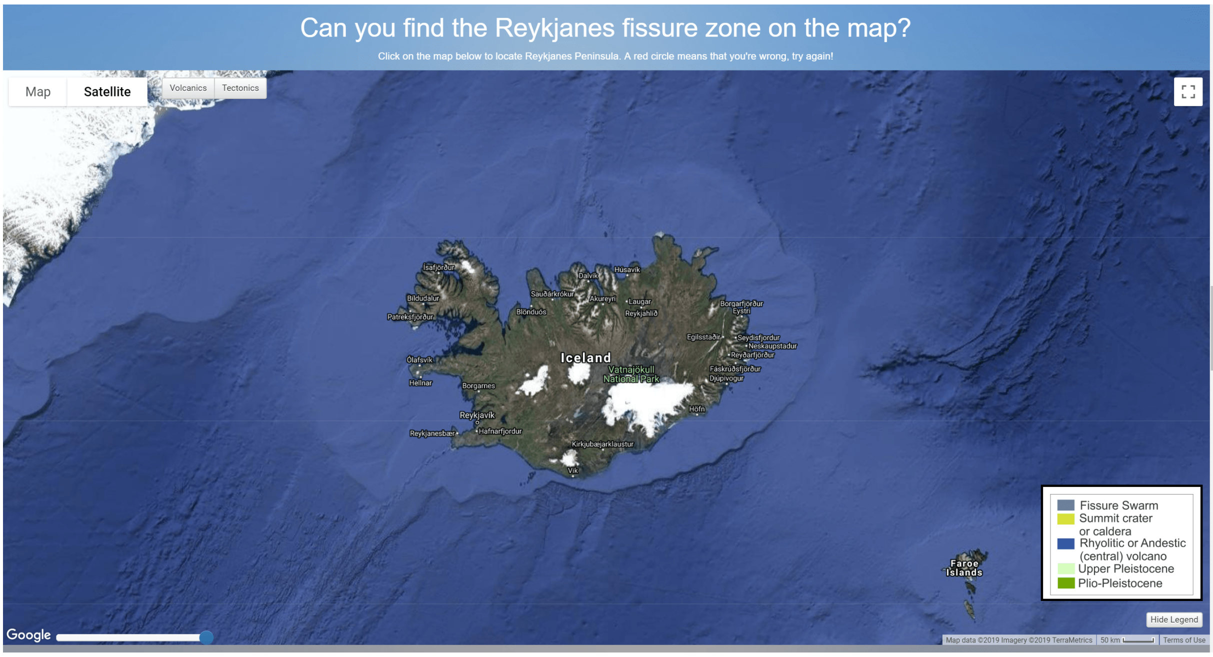

FIGURE 2.1: An interactive exercise used in the virtual fieldtrip

2.6.2 Multiple-Choice Questions

Multiple-choice questions are increasingly being used in tertiary education as a means of supplementing or replacing current assessment practices (Nicol, 2007). The growth in multiple-choice questions as a method of assessment is caused by a growing number of students, reduced resources and the increased availability of online teaching (Nicol, 2007). Multiple-choice questions can enhance opportunities for rapid feedback and allow more flexibility in delivery (Nicol, 2007).

Multiple-choice questions were the most utilised style of exercise in the virtual fieldtrip. The multiple-choice questions used in the virtual fieldtrip generally accommodated the lower levels of Bloom's taxonomy such as knowledge and comprehension (e.g., What are cinder cones made of (select more than one)?); however, some of these questions accommodated higher levels of Bloom's taxonomy such as analysis (e.g., Reorganise the following events into the correct chronological order). An example of a multiple-choice question can be observed in Figure 2.2.

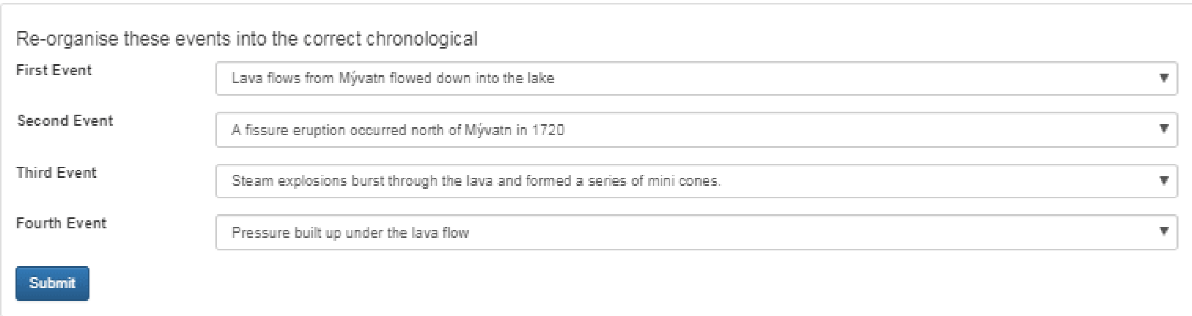

FIGURE 2.2: A multiple-choice question used in the virtual fieldtrip

2.6.3 Padlet

Padlet is an application to create an online discussion board that can be used to display information for any topic. A question can be posted on this on-line bulletin board for users to answer, discuss and rate (either up vote or down vote).

The Padlet questions in the virtual fieldtrip were generally open-ended questions, which didn't have a specific correct answer and involved any level of Bloom's taxonomy. The Padlet exercises were designed to allow students to participate in peer discussion and receive feedback by reacting and commenting on the bulletin board. Any student misconceptions or gaps in their comprehension were addressed in group discussions. An example of the Padlet layout can be observed in Appendix A.

2.7 Exercise Feedback within the Virtual Fieldtrip

Feedback is defined as information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one's performance or understanding (Hattie and Timperley, 2007). Appropriately timed feedback can be expected to be beneficial to learning (Sly, 1999). Computer-based exercises allow incorporated feedback to be delivered to large classes of students as soon as they have completed an assessment task. This immediate feedback minimises the time lag between the assessment task and the chance for students to reflect upon performance. Computer-based feedback was developed for many of the exercises within the virtual fieldtrip. This feedback was instant and pre-determined.

2.7.1 Feedback for the Interactive Exercises

Feedback for the interactive exercises in the virtual fieldtrip required students to click on a location on the map of Iceland. If students correctly answered the question they could progress to the next question. If students incorrectly answered the question at least four times they were provided with prompts to use the tectonic and volcanic overlay to help answer the question (Figure 2.3).

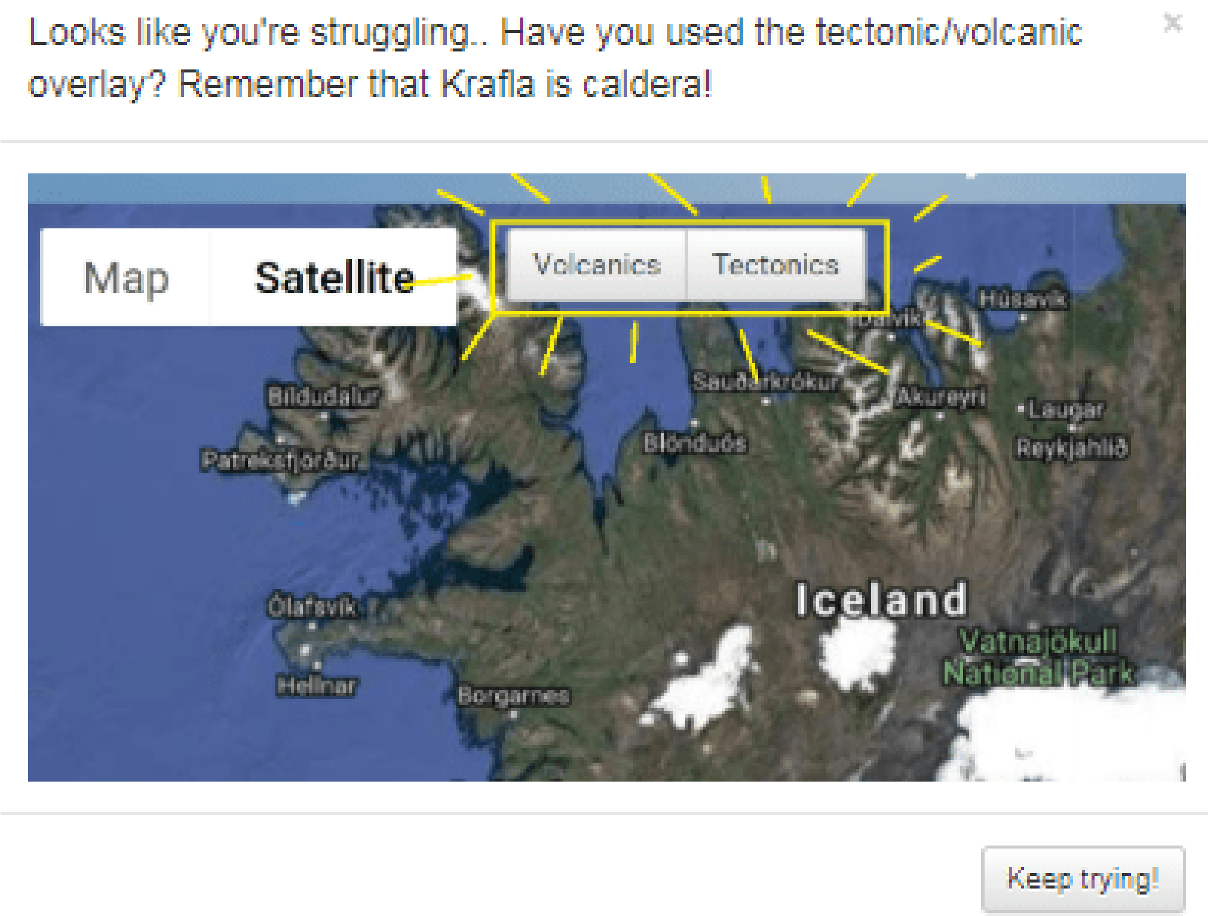

FIGURE 2.3: Feedback for an incorrect answer to an interactive exercise in the virtual fieldtrip

2.7.2 Feedback for the Multiple-Choice Questions

Feedback for the multiple-choice questions in the virtual fieldtrip required students to select one of the answers to a question and then click on the 'check answers' button to receive feedback. Students were provided feedback for both incorrect and correct answers (e.g., Figure 2.4).

The intention of the correct answer feedback was to both provide additional information and expand their understanding of the content. The intention of the incorrect answer feedback was to provide information that could help students answer the question, or to direct students to the section of the virtual fieldtrip that delivered the information required to answer the question. Following feedback, the students were required to re-select an answer until they got the question correct. This feedback informed students whether they were correct or incorrect and helped them self-correct through redirection back to the relevant information or through additional information (Hattie and Timperley, 2007).

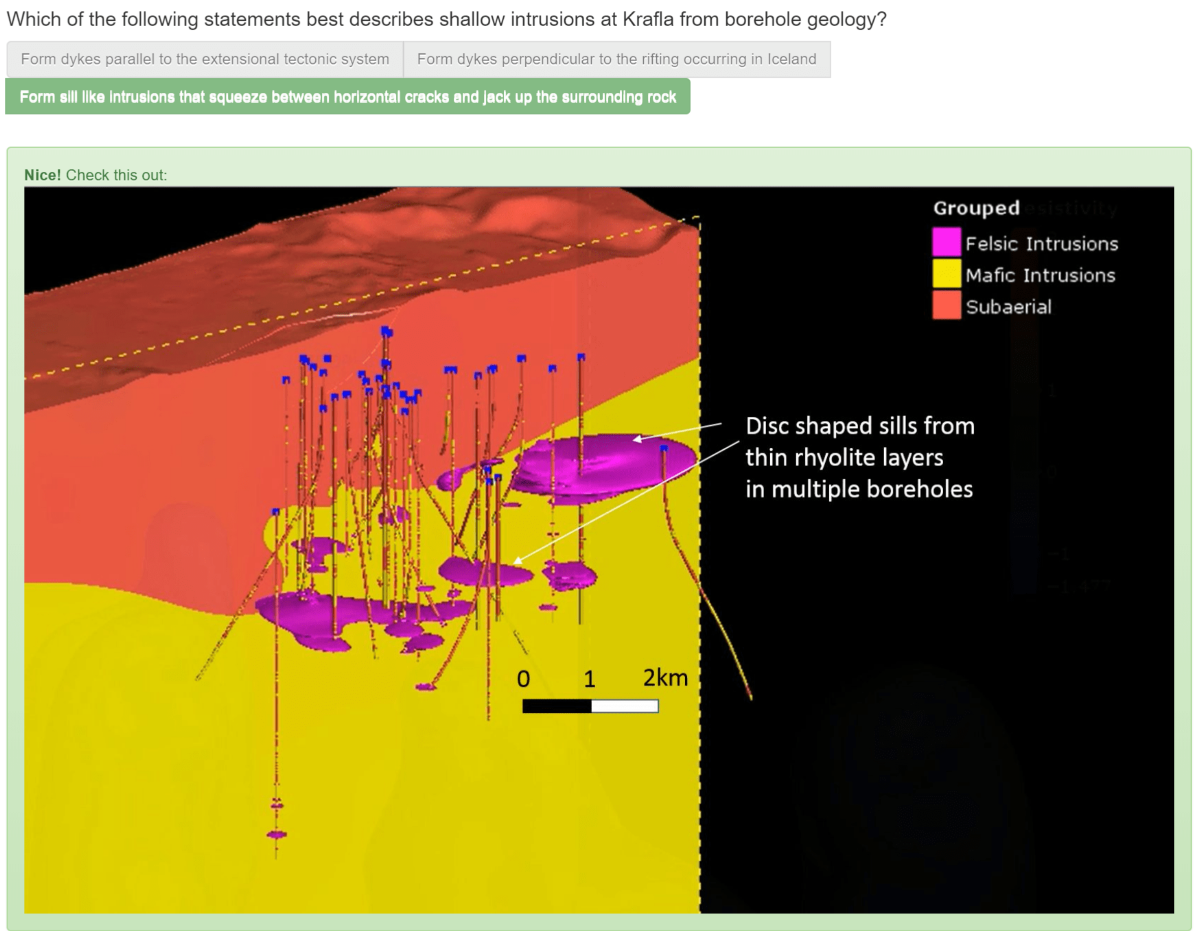

FIGURE 2.4: Feedback for a correct answer to a multiple-choice question in the virtual fieldtrip

2.7.3 Peer Feedback for the Padlet Answers

Peer feedback is a process where learners engage and communicate in rich dialogue with comments, without formal grades being given (Liu and Carless, 2006). Peer feedback enables students to take an active role in the management of their own learning. Peer interactions may encourage knowledge sharing and construction among participants (Hew, 2016). In the literature, there is evidence that peer feedback enhances student learning because students actively engage in evolving their understandings of subject matter (Falchikov, 2001). A further practical reason for peer feedback is that students could receive more and faster feedback from peers than when academics are providing feedback (G. Gibbs, 1999).

Padlet questions allowed students to answer the initial question and then discuss each other's answers to the questions in the comment section. Padlet also allowed students to up vote or down vote answers. Students were expected to comment on their classmates' answers. This essentially provided peer feedback to their classmates. Students could also receive peer feedback as they were mostly completing the exercises together within the classroom.

2.8 Active Learning in the Virtual Fieldtrip

Active learning occurs when instructors develop learner participation in classes using exercises that ask students to solve problems (e.g., multiple-choice questions or class length projects) based on newly acquired knowledge (Silberman, 1996). McConnell et al. (2017) listed three active learning strategies for geology educators: 1) students participate in activities by listening to instruction and then either doing or observing; 2) activities provide students the opportunity to reflect on their learning or facilitate interaction between the student and instructor; and 3) peer-to-peer interaction between students to complete the activity. Thus, active learning is a methodology that involves the student in observing, interacting, participating and reflecting.

Active learning requires students to be actively engaged in making sense of the material. Active participation and engagement in the classroom increases student success (Milman, 2012), and using technology as an instructional tool can be a catalyst for student learning (Chellapan and van der Meer, 2016). Student attitudes towards active learning practices have been found to be positive (Ebert-May, Brewer, and Allred, 1997; McConnell, Steer, and Owens, 2003). In the literature, active learning increases student performance in a range of disciplines including science, engineering and mathematics. This improves student learning and contributes to increased retention rates (McConnell et al., 2017).

The virtual fieldtrip was inherently an active learning environment. Students could not continue with the trip without making observations; estimating measurements from instructional videos of lava flows; and discussing alternative explanations for the magma system beneath Krafla caldera. This shows that students were participating in activities by listening to instruction within the instructional videos (McConnell et al., 2017).

Co-operative learning was also encouraged during in-class discussions. Students were encouraged to work in informal groups and discuss their answers with their peers. This shows that students were involved in peer-to-peer interaction to complete the exercise (McConnell et al., 2017).

Following the completion of each location, students discussed in greater depth what they had learned in the virtual fieldtrip with their peers and the course instructor. This provided opportunities for student reflection on their learning and facilitated interaction with the instructor (McConnell et al., 2017).

2.9 Content Delivery in the Virtual Fieldtrip

The technological components that make up the virtual fieldtrip include instructional videos, digital elevation models (DEMs), aerial imagery, and structure from motion (SFM) models ranging in size from outcrop to rock scale. These components were all included in an intuitive, familiar website interface. These technological components allowed for the recreation of an immersive experience that was similar to geology fieldwork and an authentic learning experience.

2.9.1 3D Visualisations

There are a variety of computer-based tools that can be used to enhance 3D visualisation. Two valuable tools to display geological maps and field data are DEMs (e.g., Figure 2.5) and SfM models (e.g., Figure 2.6). One of the advantages of utilising 3D visualisations is that it allows students to view hard to access outcrops in the classroom (Mountney, 2009), and permits virtual access to any place on Earth. The implementation of 3D visualisations within geology and geography coursework is well established in the literature (e.g., Anthamatten and Ziegler, 2006; Mountney, 2009). Studies have found that 3D visualisations have a beneficial impact on student learning and offer a range of teaching opportunities (McCaffrey, Feely, Hennessy, and Thompson, 2008).

Digital Elevation Models (DEMs)

A DEM is the digital representation of the land surface elevation with respect to any reference datum. DEMs are available for most regions of the developed world. ArcScene displays DEMs, which provide an alternative means to present and interpret geological maps and field data (Whitmeyer et al., 2009).

The DEMs in the virtual fieldtrip were draped with satellite imagery on top. At the start of each virtual fieldtrip location, students were taken on a 'fly-over', where they were transported to each location using a 3D world built from DEMs and satellite imagery. Students could pause and rotate the animation at any point. Students were initially taken on a fly-over from New Zealand to Reykjanes, Iceland, for the first stop of the virtual fieldtrip. For the other locations in the virtual fieldtrip students were transported around Iceland using this fly-over method. The users were encouraged to click 'initiate the fly-over'. The fly-over represents the travel to a field location, which would normally occur in a van or plane. This was used so students could identify and locate where they were, but also get an idea of the distances and scales involved.

DEMs were also used in each location of the virtual fieldtrip to showcase different landscape features such as tuff cones, caldera margins and lava flows (e.g., Figure 2.5). These DEMs allowed the students to rotate and zoom in on geological features within each location and analyse them.

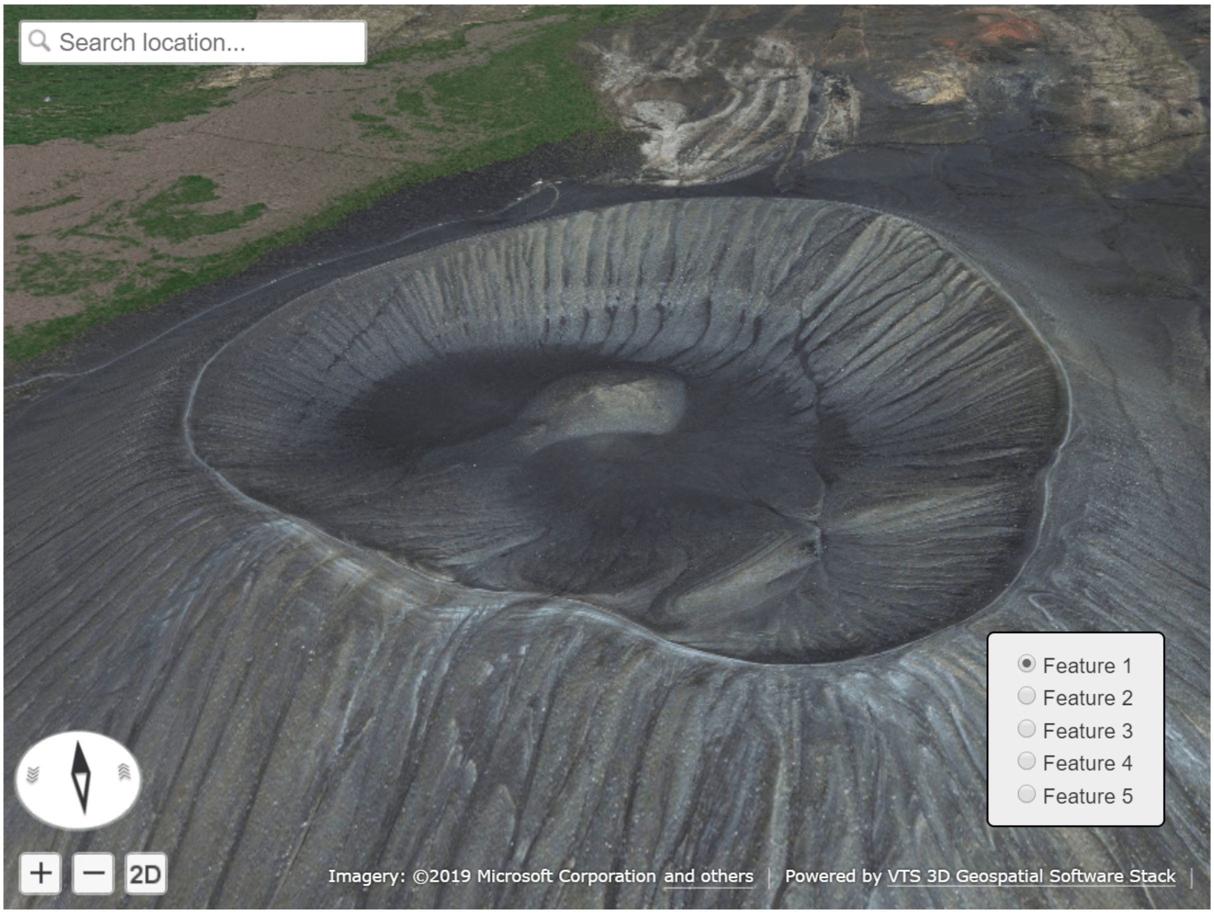

FIGURE 2.5: DEM of a cinder cone at Krafla

Structure from Motion (SfM)

SfM operates under the same tenets as stereoscopic photogrammetry, where 3D structure can be resolved from a series of overlapping, offset images. This approach is most suited to a set of images with a high degree of overlap that capture full 3D structure of the scene viewed from a range of positions or images derived from a moving system (e.g., a drone) (Westoby, Brasington, Glasser, Hambrey, and Reynolds, 2012). From this data a 3D point-cloud can be generated from these photosets. These point-clouds allow users to rotate, pan and zoom in 3D around a geological outcrop. Point-clouds have been used in student instruction and have the potential to supplement traditional educational content and aid in the improvement of student literacy (e.g., McCaffrey et al., 2008).

A SfM model generated from drone photography was used at the Krafla location of the virtual fieldtrip (e.g., Figure 2.6). This SfM was used so that students could pan, zoom and rotate the point cloud to identify volcanic features within the outcrop.

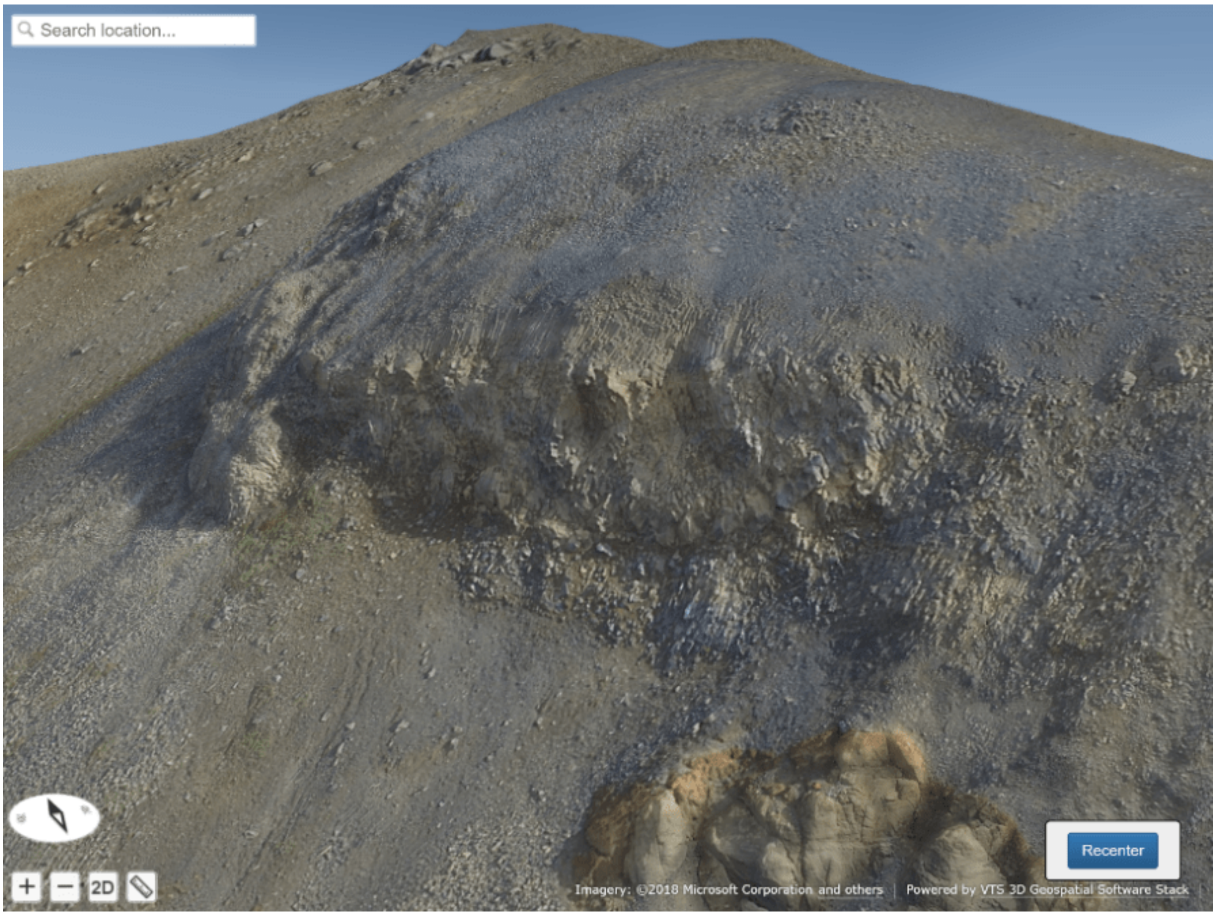

FIGURE 2.6: Point-cloud of the outcrop at Hrafntinnuhryggur

Rock Models

Images of rock samples from each location were used in the virtual fieldtrip. This allowed students to match a rock with the associated outcrop. Some of these rock samples were converted into 3D rock models (Figure 2.7) using the SfM process. This allowed students to rotate and zoom in on the rock sample to identify structural, textural and compositional characteristics.

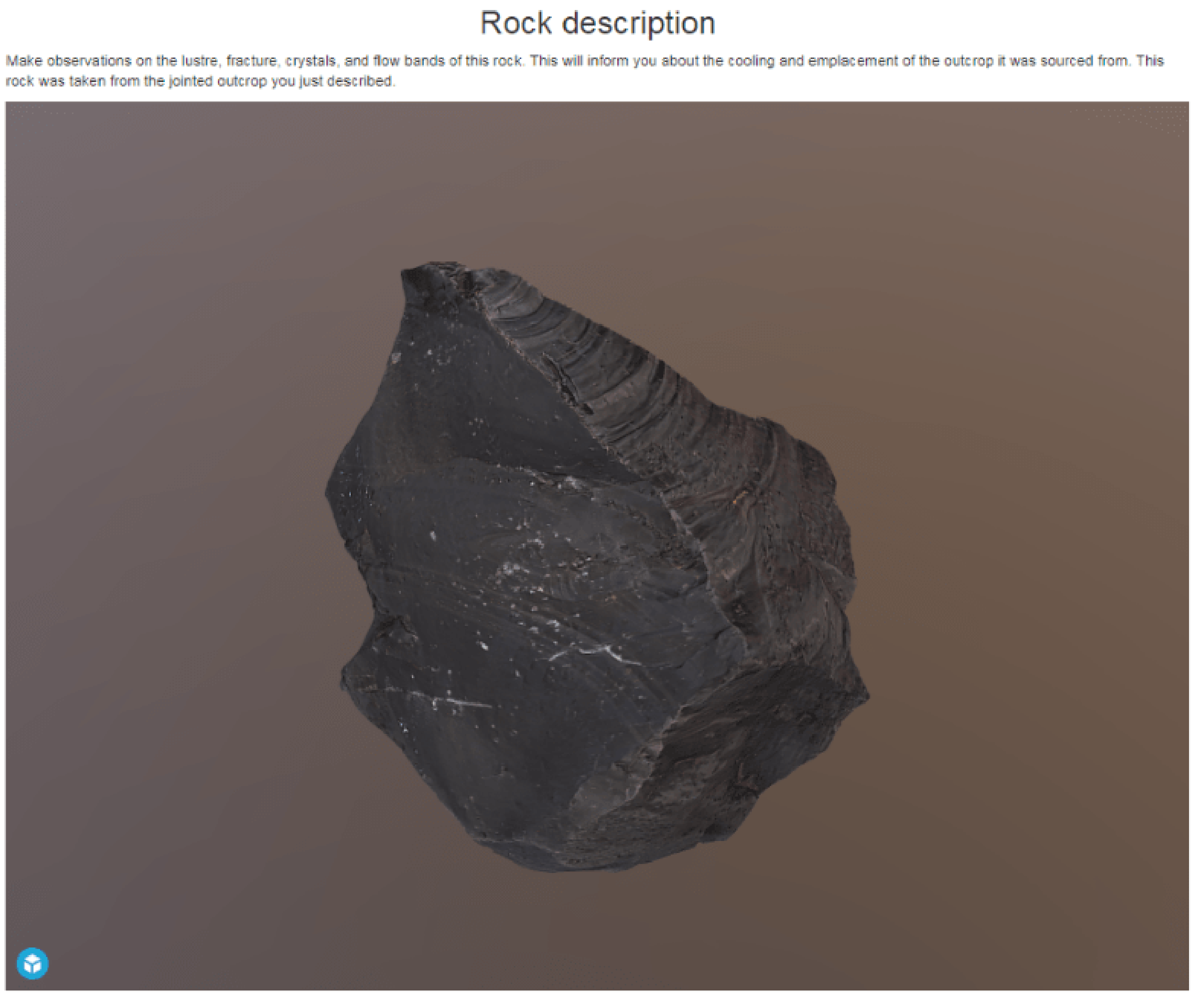

FIGURE 2.7: Rock model of obsidian collected from Krafla

2.9.2 Instructional Videos

Instructional videos are videos that either demonstrate a process, transfer knowledge or explain a concept. Instructional videos are designed to aid understanding, facilitate learning and give learners the ability to pause, rewind and fast-forward without having to consider the learning styles or pace of fellow learners (Little, 2015). In case studies, students have found instructional videos to be positive learning tools (Little, 2015). The use of videos have been shown to increase students attention and engagement (e.g., Green et al., 2003; Jha, Widdowson, and Duffy, 2002; Zhang, Zhou, Briggs, and Nunamaker Jr, 2006); increase motivation and self-efficacy (Bennett and Glover, 2008); and improve understanding (e.g., Choi and Johnson, 2005; Reisslein, Seeling, and Reisslein, 2005; Zhang et al., 2006).

The instructional videos created for the virtual fieldtrip were based on the description given in J. P. Jones, McConnell, Wiggen, and Bedward (2019). They were short, content-related videos designed to convey concepts of volcanology. The videos were typically five to seven minutes long. They followed a standard format consisting of a mix of learning objectives, content topics, brief text coupled with images (e.g., maps, diagrams, models, geologic features) and embedded video clips. The instructional videos were used to engage students and avoid students losing concentration.

Instructional videos were utilised throughout the virtual fieldtrip (e.g., Figure 2.8). At the start of each location, instructional videos were used to introduce the location specific intended learning outcomes. Throughout each location, these instructional videos were used to describe, explain and discuss a range of relevant volcanic features and processes (e.g., a'a' and pahoehoe lava flows) utilising commentary from expert volcanologists. Most of these instructional videos were filmed on location in Iceland; however, a couple of the instructional videos were Skype interviews.

FIGURE 2.8: An instructional video for the Reykjanes location in the virtual fieldtrip

360 Videos

One particular type of instructional video is a 360 video. 360 videos are made using omnidirectional cameras that capture a sphere around the camera. Viewers get an immersive experience by freely changing their field of view around the sphere. 360 videos can also render a virtual reality environment via a head-mounted display - allowing an immersive experience and giving a realistic view of the surrounding. 360 Videos can now be viewed on everyday devices (e.g., laptops, phones) via online video services such as YouTube.

360 videos were utilised in each location. The 360 videos included expert commentary and were used to explain volcanic features and processes. The 360 videos allowed students to pan around the volcanic landscape, and zoom in and focus on certain features. These 360 videos were concise (between two and seven minutes). The instructor used voice and physical cues to highlight the important volcanological features and processes while filming the 360 videos.

2.10 Implementation of the Virtual Fieldtrip

The virtual fieldtrip was implemented in October 2018, over the course of four regular lecture sessions and one laboratory session in GEOL336. Participation in the virtual fieldtrip was worth ten percent of each student's total GEOL336 grade. Students participated in the virtual fieldtrip several weeks after the data was collected, compiled and processed.

Chapter 3

The In-Class Exercise and Reflective Questionnaire

3.1 Background Literature for the In-Class Exercise

3.1.1 Sketching

Sketching is commonly used by geologists to make predictions and evaluate hypotheses (Gagnier, Atit, Ormand, and Shipley, 2017). Sketches are an important way to record observations, organise knowledge, visualise geometries of rock units, and convey ideas to others (Rudwick, 1976). The purpose of geological field sketching is to record observations, which leads to the development of interpretations and hypotheses. Sketching an outcrop in the field is the first step in the observation process and encourages a logical and systematic approach to observing. They are generally produced while carrying out ongoing interpretations, normally while in the field (McClay, 2013 p. 35). A field sketch can be accompanied by a few interpretative ideas in the form of notes or additional interpretative cartoon sketches (Kruhl, 2017 p. 6).

Sketching has been a component of geology teaching and learning for a long time, particularly in fieldwork (e.g., J. K. Johnson and Reynolds, 2005; Ormand et al., 2017). Sketching can also be used as a pedagogical tool to help students reason about 3D structures that are not visible (Gagnier et al., 2017). Geology educators have used sketching to develop and assess student understanding of key concepts (e.g., J. K. Johnson and Reynolds, 2005; Garnier et al., 2017). Therefore, sketching is useful as it makes a student's thinking visible to the instructor.

Sketching is a powerful assessment tool that can reveal details about both the complexity and quality of student understanding, and can also reveal misunderstandings of science phenomena that are often not detected in more traditional assessment instruments (Cooper, Stieff, and DeSutter, 2017). The value of student sketches has been demonstrated in a study focused on plate tectonics. Gobert and Clement (1999) found students who produced sketches as they read performed better than students who only wrote summaries or simply read the text. J. K. Johnson and Reynolds (2005) reported that students who either sketched or wrote explanations as they read were better able to explain the processes; whereas, the students who wrote summaries tended to have a recall of the material but not a good working knowledge. Educational research indicates that producing a sketch promotes better student comprehension and permits students to better use this knowledge to investigate the underlying geological processes and principles (J. K. Johnson and Reynolds, 2005).

Predictive Sketching

Predictive sketching is the use of sketching to make a prediction (e.g., a prediction on what a cross-section through a 3D visualisation of a geological structure will look like). Based on Gagnier et al. (2017), sketching spatial inferences involves a number of cognitive processes that support understanding of diagrams that convey 3D spatial relations. First, the sketcher must visualise and focus on the spatial relationships in the object and generate a spatial prediction regarding this visualisation. The act of sketching supports this visualisation as the sketch is being created. Second, the prediction must be aligned to the diagram space by the sketcher. Third, a coherent representation in which the lines consistently correspond to some feature of the world must be made by the sketcher (Van Meter and Garner, 2005).

Cognitive science research on the use of sketching has shown that predictive sketching, alongside immediate feedback on sketch accuracy, can be a powerful pedagogical tool (Gagnier et al., 2017). If students make a predictive cross-sectional sketch, then immediately compare their sketch to the correct answer and continue to make predictive sketches, they can get significantly better at visualising cross-sections of geological block diagrams (Gagnier et al., 2017).

Concept Sketching

A concept sketch illustrates the main aspects of a concept or system, annotated with concise but complete labels. These labels can identify features, depict processes and characterise the relationships between features and processes (J. K. Johnson and Reynolds, 2005). Concept sketches in geology are often cross-sections but can be completed in map-view or a range of perspective views. Concept sketches require students to contend with their internal conceptualisations and spatial orientations (J. K. Johnson and Reynolds, 2005).

3.1.2 Interpretation

Frodeman (1995) described geology as a historical and interpretive science. Geological interpretation begins at the data collection stage. Whilst in the field, a geologist approaches an outcrop with the intention of collecting information to observe, derive, or test a hypothesis (Parcell and Parcell, 2009). For example, a rock can be characterised by certain properties that have meaning to a geologist and can lead to an interpretation. This rock may have particular characteristics such as texture, mineralogy or color. This is recognised by geologists and point them to an interpretation or greater meaning (Parcell and Parcell, 2009).

To reach an interpretation, geologists place the rock's particular characteristics within the framework of their education, prior experience, conceptual models or hypotheses. These interpretations are therefore the result of detailed processes where the geologist collects and records the raw field-data and observations and then interprets those data based on geological theories and geometric relationships (Clarke, 2004). The geologist can then interpolate between or extrapolate beyond the data to 'complete the picture', and can extend this information to other interpretations or other parts of the same interpretation (Clarke, 2004). Thus, the geologists understanding of a region is based on the interpretation of the individual field outcrops in that region, and the interpretation of an individual layer within an outcrop is based on the geologists understanding of the sediments and structures that make up that layer (Frodeman, 1995).

Geologic interpretation skills are often taught throughout undergraduate and graduate geology classes to help students understand the relationship between the spatial characteristics of the geologic region. Many undergraduate geology students have not reached the stage to make observations and interpretations in the field. It is important to develop these interpretation and observational skills in the training of geologists, as understanding how interpretation skills are better developed alongside geological concepts and techniques is crucial for the training of future geologists (Bond, Philo, and Shipton, 2011).

3.2 Context for the In-Class Exercise

Sketching is taught at the University of Canterbury in the following courses: 1) GEOL115: The Dynamic Earth System; 2) GEOL240: Field Studies A – Mapping; and 3) GEOL241: Field Studies B – Field Techniques. GEOL115 is a compulsory course in the geology curriculum at the University of Canterbury. GEOL240 and GEOL241 are non-compulsory courses for geology students at the University of Canterbury. They are not pre-requisites for GEOL336; however, they are common papers taken by undergraduates majoring in geology at the University of Canterbury. Sketching is commonly assessed in student field notebooks during field excursions for these courses.

Mogk and Goodwin (2012) p. 145 noted: "the field setting is where geoscientists initially translate nature into culture, i.e., where we begin to create representations based on communally tested and accepted practices (i.e., maps, graphs, visualizations) that explain, confirm, rationalize, and externalize our understanding of Earth". Organising a fieldtrip for GEOL336 was not possible due to time constraints and logistical problems. Instead of sketching and interpreting the Sumner outcrop in the field, students were provided with a photograph of the Sumner outcrop in the in-class exercise (Appendix B). Outcrop photographs are often used in geology to illustrate geologic features (C. L. Johnson, Semple, and Creem-Regehr, 2013), and they make excellent prompts for sketching (J. K. Johnson and Reynolds, 2005).

3.3 In-Class Exercise Design

The in-class exercise questions were aligned with the intended learning outcomes for GEOL336 and the virtual fieldtrip (Table 3.1). This was to ensure that the in-class exercise questions assessed the material taught in both the GEOL336 lava flow module and the virtual fieldtrip.

In-Class Exercise Questions	GEOL336 Iceland Virtual Fieldtrip Intended Learning Outcomes	GEOL336 Intended Learning Outcomes
Sketch and annotate the key geological features of this outcrop. (Q1)	- Record systematic and detailed observations of an outcrop and rock of a typical cone fed a'a' flow.	- Discuss physical volcanological processes with relevance to magma properties.
Which of the labels in your sketch are most important to a volcanologist? Why? (Q2)	- Record systematic and detailed observations of an outcrop and a rock of a typical fissure fed eruption of a pahoehoe flow.	- Identify and classify igneous rocks and their geological environments.
Produce an interpretative sketch of lava flow A in cross-section, perpendicular to the cliff face (side view) and annotate the key geologic features and processes that you might expect from this perspective. (Q3)		
Produce an interpretive sketch of lava flow A in map view (birds-eye view) and annotate the key geological features and processes that you might expect from this perspective. (Q4)		

TABLE 3.1: Alignment of the in-class exercise questions with the intended learning outcomes of GEOL336 and the virtual fieldtrip

3.4 The In-Class Exercise

Question one (Q1) required students to produce an observational sketch of the Sumner outcrop and annotate the observed geological features. Q1 of the in-class exercise can be observed in Table 3.1.

Question two (Q2) required students to categorise and evaluate the geological features they annotated in their observational sketch. Q2 of the in-class exercise can be observed in Table 3.1.

Question three (Q3) and Question four (Q4) required students to sketch lava flow (A) from a different perspective, and use the observations they made in the Q1 sketch to interpret the geological features from a different perspective. This required students to apply and interpret the observed geological features. Q3 and Q4 of the in-class exercise can be observed in Table 3.1.

The interpretive sketching exercises were designed utilising components of both perspective and concept sketching. An interpretive sketch conveys a range of annotated features, structures and processes, which have been interpreted within the outcrop. Interpretive sketches require students to contend with their internal conceptualisations and spatial orientations of the phenomena (in this case lava flows), and make a prediction of what a cross section through the outcrop may look like. Interpretive sketches can be drawn in a range of different perspectives (such as map-view and side-view in this exercise). A copy of the in-class exercise can be found in Appendix B.

3.4.1 Limitations of the In-Class Exercise

One limitation of the in-class exercise was that students were not provided with rock samples to help with their interpretation. As stated in Parcell and Parcell (2009), rocks may have particular characteristics such as texture or mineralogy, which cannot be observed in a photograph of an outcrop.

3.5 Implementation of the In-Class Exercise

The same in-class exercise was completed by students twice in GEOL336. The first in-class exercise was completed by students following the GEOL336 lava flow module (Table 2.1). This was done so that the content required to complete the in-class exercise had been taught in the lava flow module. The second in-class exercise was completed by students following the Reykjanes and Heimaey locations (the two locations that focused on lava flows) in the virtual fieldtrip (Table 2.1). This was done so that the content required to complete the in-class exercise had been taught for a second time in the virtual fieldtrip. Students were allocated thirty minutes to complete each in-class exercise.

3.6 Measuring Student Performance in the In-Class Exercise

3.6.1 Rubric Development

Rubrics are a common assessment tool used in tertiary education (Reddy and Andrade, 2010). Well-designed rubrics enable assessors to divide an exercise into its separate parts and to clearly and explicitly communicate expectations to students. Popham (1997) proposed that a rubric must have three essential elements. These include evaluative criteria, quality definitions for those criteria at certain levels and a scoring strategy.

Evaluation criteria reflect the processes and content judged to be important. Scores derived from the assessment serve as indicators of underlying processes and knowledge in students (Parke, 2001). The evaluation criteria for the in-class exercise marking rubric included observational sketching (Q1), annotated sketch content (Q1), annotated geological content (Q1), interpretive sketching in side-view (Q3), feature interpretation in side-view (Q3), interpretive sketching in map-view (Q4) and feature interpretation in map-view (Q4).

Quality definitions illuminate what instructors and courses expect of the learner in terms of skill or proficiency demonstration at varying levels of attainment (i.e., expert, intermediary, novice) (Sandberg and Kecskes, 2017). Quality definitions were included for each evaluation criteria under the varying levels of attainment, as can be observed in Appendix C.

Scoring strategies involve a consistent scale for interpreting quality judgements associated with learning attainment and demonstration (Reddy and Andrade, 2010). The scoring strategy for the in-class exercise marking rubric was one point for each correctly labelled feature or process. There were associated levels of learning attainment based on the number of correctly labelled geological features, structures and processes.

To develop the marking rubric for the in-class exercise, eight members of the volcanology group at the University of Canterbury (e.g., post-graduate students, post-doctoral fellows and academics) completed the in-class exercise. These members of the volcanology group did not participate in the virtual fieldtrip prior to completing the in-class exercise. However, these members of the volcanology group are experts within volcanology and petrology; therefore, they were able to correctly identify the features and structures in the Sumner outcrop. The in-class exercises completed by the volcanology group members were collected and collated to form a model answer. If the same feature was identified in at least two of these expert sketches they were included in the marking rubric. A copy of the in-class exercise marking rubric can be found in Appendix C.

3.6.2 Q1 Marking Rubric

The marking rubric for Q1 was divided into three parts. A copy of the Q1 marking rubric can be found in Appendix C.

The first part was "observational sketching". This part focused on the detail and presentation of each students observational sketch. A maximum of three points was awarded for this part (with no partial marks).

The second part was "annotated sketch content". This part focused on features that are included on any geological sketch. A list of the annotated sketch features can be found in Appendix C.A maximum of three points was awarded for this part (with no partial marks).

The third part was "annotated geological content". This part focused on the features which students observed in the Sumner outcrop and annotated on their observational sketch. A list of the geological features included in the marking rubric for Q1 can be found in Appendix C. There were a total of fourteen geological features included in the model answer of the Sumner outcrop for Q1. This would have been unobtainable for the GEOL336 students, as none of the experts labelled more than ten features in their expert-level answers. Therefore, a maximum of ten points was awarded for this part (with no partial marks). To receive a point, the position of one of the geological features or processes needed to be annotated correctly on the sketch. In some cases, the geological features appeared twice within the outcrop (e.g., columnar jointing and channels). One point was awarded for annotating at least one of these geological features or processes. Additional points could be awarded for annotated geological features, which were not included in the marking rubric but were potentially correct. The decision to award additional points was made by the in-class exercise marker.

3.6.3 Q3 Marking Rubric

The marking rubric for Q3 of the in-class exercise was divided into two parts. A copy of the Q3 marking rubric can be found in Appendix C.

The first part was "interpretive sketch in side-view". This part focused on the presentation of the interpretive sketch in side-view. A maximum of three points could be awarded for this part (with no partial marks).

The second part was "feature interpretation in side-view". This part focused on the geological features that students interpreted based on the observed geological features. These were annotated on the interpretive sketch in side-view. A list of the interpreted geological features in side-view included in the marking rubric can be found in Appendix C. There was a total of ten geological features included in the model answer of the Sumner outcrop for Q3. This would have been unobtainable for the GEOL336 students, as none of the experts labelled more than eight features in their expert-level answers. Therefore, a maximum of eight points was awarded for this part (with no partial marks). One point was awarded for annotating at least one of these geological features or processes. Additional points could be awarded for interpreted features, which were not included in the marking rubric but were potentially correct. The decision to award additional points was made by the in-class exercise marker.

3.6.4 Q4 Marking Rubric

The marking rubric for Q4 of the in-class exercise was divided into two parts. A copy of the Q4 marking rubric can be found in Appendix C.

The first part was "interpretive sketch in map-view". This part focused on the detail and presentation in the interpretive sketch in map-view. A maximum of three points was awarded for this part (with no partial marks).

The second part was "feature interpretation in map-view". This part focused on the geological features that students interpreted based on the observed geological features. These were annotated on the interpretive sketch in map-view. A list of the interpreted geological features in map-view included in the marking rubric can be found in Appendix C. There was a total of ten geological features included in the model answer of the Sumner outcrop for Q4. This would have been unobtainable for the GEOL336 students, as none of the experts labelled more than eight features in their expert-level answers. Therefore, a maximum of eight points was awarded for this part (with no partial marks). One point was awarded for annotating at least one of these geological features or processes. Additional points could be awarded for interpreted features, which were not included in the marking rubric but were potentially correct. The decision to award additional points was made by the in-class exercise marker.

3.7 Limitations of the Marking Rubric

One limitation of the in-class exercise marking rubric was that it was difficult to test the effectiveness of the virtual fieldtrip to aid sketching and interpretation, as these skills were required for each in-class exercise question. To analyse the effects the virtual fieldtrip had on these skills, the marking rubric divided each question into parts so that sketching and interpretation could be assessed for each question.

The marking rubric parts for sketching were observational sketching (Q1), interpretive sketching in side-view (Q3) and interpretive sketching in map-view (Q4). The parts for annotation were annotated sketch content (Q1) and annotated geological content (Q1). The parts for interpretation were feature interpretation in side-view (Q3), interpretive sketching in side-view (Q3), feature interpretation in map-view (Q4) and interpretive sketching in map-view (Q4).

These parts identified the main skills used in each question (e.g., in observational sketching, sketching was the main skill); however, not all the skills were represented in each of these parts. For example, the observational sketch also required some geological interpretation. As noted in Kruhl (2017) (p. 6) sketches always contain an interpretation, because even an omission in a drawing is an interpretation. However, the observational sketch required less interpretation than both interpretive sketching in side-view (Q3) and interpretive sketching in map-view (Q4), as these parts required students to interpret the geological features based on the features they identified in their observational sketch.

3.8 Marking the In-Class Exercise

The first and second in-class exercise were collected and graded by the GEOL336 course co-ordinator following completion. Each in-class exercise was worth 0.5 percent (participation marks) towards each students total GEOL336 grade. The Canterbury ID card number on each in-class exercise allowed each student's in-class exercises to be matched. The matched in-class exercises produced by students who agreed to participate in this research were given new identification numbers to replace the original student ID number. These new identification numbers were used to uphold participant confidentiality. Once these new ID numbers replaced the Canterbury ID number, the in-class exercises were graded for this research using the marking rubric. The grading was completed by a University of Canterbury PhD student.

3.9 Background Literature for the Reflective Questionnaire

Reflection is an activity in which people recapture an experience, think about it, then evaluate it, and demonstrate learning that can be taken forward. Students that have been taught new information or had new "doing" or "observing" experiences need time to reflect in order to decide what meaning to give to these learning activities. Without this reflection, students have learned something but they have not made that learning fully meaningful to themselves (Fink, 2013, p. 116). As stated in McConnell et al. (2017), reflection-based activities are a component of active learning environments. Schwartz, Lederman, and Crawford (2004) indicate that teaching in the context of hands-on activities requires discussions and opportunities for reflection in order for students to develop a more complete understanding of the process of science.

There are a range of activities that encourage student reflection. Reflective writing focuses on the students learning experience and helps to identify the significance and meaning of a given learning experience (Fink, 2013, p. 116). One use of reflective questions is they provide students with an opportunity to reflect on their overall understanding of both how an activity fits within the scientific process framework and how material is related to the knowledge gained in previous activities (Surpless, Bushey, and Halx, 2014). Therefore, a reflective questionnaire can be used guide students in their reflective process, whilst informing the researcher on students perceptions of their learning.

3.10 The Reflective Questionnaire

The reflective questionnaire prompted students to reflect on the overall learning experience of the virtual fieldtrip upon its completion. When reflection is used in context it can help students make meaning of a learning event (Boud and Walker, 1998). The questions within the reflective questionnaire probed which aspects of the virtual fieldtrip aided students in the in-class exercise.

The reflective questionnaire also provided constructive feedback to improve future iterations of the virtual fieldtrip. Reflection on what happened can help formulate modifications, which in turn will improve alignment of intended learning outcomes and promote better future learning (Boyle et al., 2007). A copy of the reflective questionnaire can be found in Appendix D.

3.11 Implementation of the Reflective Questionnaire

Following the second in-class exercise, students completed the reflective questionnaire (Table 2.1). The reflective questionnaire was an integral part of the GEOL336 course assessment and was worth ten percent of the final course grade. The reflective questionnaire took students thirty minutes to complete. The reflective questionnaire was collected following completion and graded by the course co-ordinator for GEOL336. The reflective questionnaires were identified using each student's ID number. This allowed for grades to be given to the reflective questionnaire and to match each student's reflective questionnaire with the in-class exercises. Once this was completed, the reflective questionnaires produced by students who agreed to participate in this study were given new identification numbers to replace the original student ID number. These new identification numbers were used to uphold participant confidentiality. Once these new ID numbers replaced the Canterbury ID number the reflective questionnaire was coded by the researcher.

3.12 Ethics

Following the completion of the reflective questionnaire, students were approached to participate in this research study, as per the approved University of Canterbury ethics application. Each student was handed a consent form and information sheet. Students who agreed to participate in the study handed the consent form into the researcher. Following the grades being allocated to the assessment, the researcher requested the two in-class exercises and reflective questionnaire produced by the students who agreed to participate in the research study. The in-class exercises and reflective questionnaires produced by students who agreed to participate in this study were used as research data (n=44 for the in-class exercise, n=49 for the reflective questionnaire and n=42 for the combination of quantitative and qualitative data). The in-class exercises and reflective questionnaires produced by students who didn't agree to participate in the research study were not used as research data. The in-class exercises and reflective questionnaires not used for this research study were stored by the GEOL336 co-ordinator.

Chapter 4

Methodology and Results

4.1 Methodology for Analysing the In-Class Exercise Data

Hake (1998) published a seminal work that provides education researchers with a sound metric to normalise each student's individualised learning 'change' and eliminates the problem of high correlation between pre-test and post-test scores. Conceptual diagnostic tests are used to measure course effectiveness by assessing student understanding about a particular concept before and after instruction. This is often called pre-test and post-test design. Hake (1998) showed that interactive engagement methods in physics led to higher gains than traditional lecture-based methods.

Learning gains (commonly shortened to 'gains') were used to analyse the data in this research to avoid any correlation between the first and second in-class exercises, and to determine the extent of learning in the student population. Learning gains were calculated using the following equation:

$$Learning\ Gains = \frac{(Post\ test\ (\%) - Pre\ test\ (\%)}{100\ (\%) - Pre\ test\ (\%)}$$

In this research, the pre-test was the first in-class exercise and the post-test was the second in-class exercise. This measured the learning gains of the students following the virtual fieldtrip. Learning gains were calculated for each of the marking rubric parts (e.g., observational sketching (Q1), interpretive sketching in side-view (Q3), interpretive sketching in map-view (Q4), annotated sketch content (Q1), annotated geological content (Q1), feature interpretation in side-view (Q3) and feature interpretation in map-view (Q4)). The standard error was also calculated based on the learning gains for each of the marking rubric parts.

Positive gains indicate that the student in question scored higher on the second in-class exercise than on the first in-class exercise. Negative gains indicate that the student in question scored lower on the second in-class exercise than on first in-class exercise. Averaging an entire student population will show whether most students acquired a positive learning gain or a negative learning gain. Plotting learning gains against the first in-class exercise scores will show any relationship between learning gains and first in-class exercise scores.

For example: Student A receives a first in-class exercise score of 30 percent and a second in-class exercise score of 51 percent (change of 21 percent). This results in a 0.3 gain. Student B receives 75 percent on the first in-class exercise and 82.5 percent on the second in-class exercise resulting in the same gain (of 0.3). The change in learning is dependent on each students 'starting point'. It is more difficult for Student B to gain 10 percent of the total grade than it is for Student A. Normalising the change in the in-class exercise scores allows for the comparison of one student to another, and assesses how much the students learned. The normalised gain for each student is calculated and then averaged. This is called average of gains.

4.2 Methodology for Analysing the Reflective Questionnaire Data

Qualitative analysis allows room for multiple interpretations while avoiding objectivity (Feig, 2011); however, it requires more effort in both data generation and the analysis process. Coding is one way to analyse qualitative data. Coding is a way of indexing or categorising the text in order to establish a framework of thematic ideas (G. R. Gibbs, 2007).

The reflective questionnaire and Q2 of the in-class exercise were coded and assigned to relevant research themes using Microsoft Excel. The first pass was predominantly concerned with identifying the common themes within each question concerned with the content guided by the aims and objectives of this research. Following the first round of coding, patterns and themes were detected and the research could begin to generalise (e.g., by counting the frequencies of codes) (Cohen, Manion, and Morrison, 2002). The second pass was concerned with reading back through the data and separating out individual phrases to match with the identified patterns and themes. This was a way to check the identified common themes were present. These were assigned in verbatim or unique categories (i.e., parroting phrases exactly from the class dialogue) (Dohaney et al., 2015).

4.3 Learning Gains for the In-Class Exercise

4.3.1 Observational Sketching (Q1)

The average learning gain for observational sketching (Q1) was 0.11 ± 0.06. Thirty-four students scored the same in both the first and second in-class exercises (i.e., learning gains of 0) (Figure 4.1).

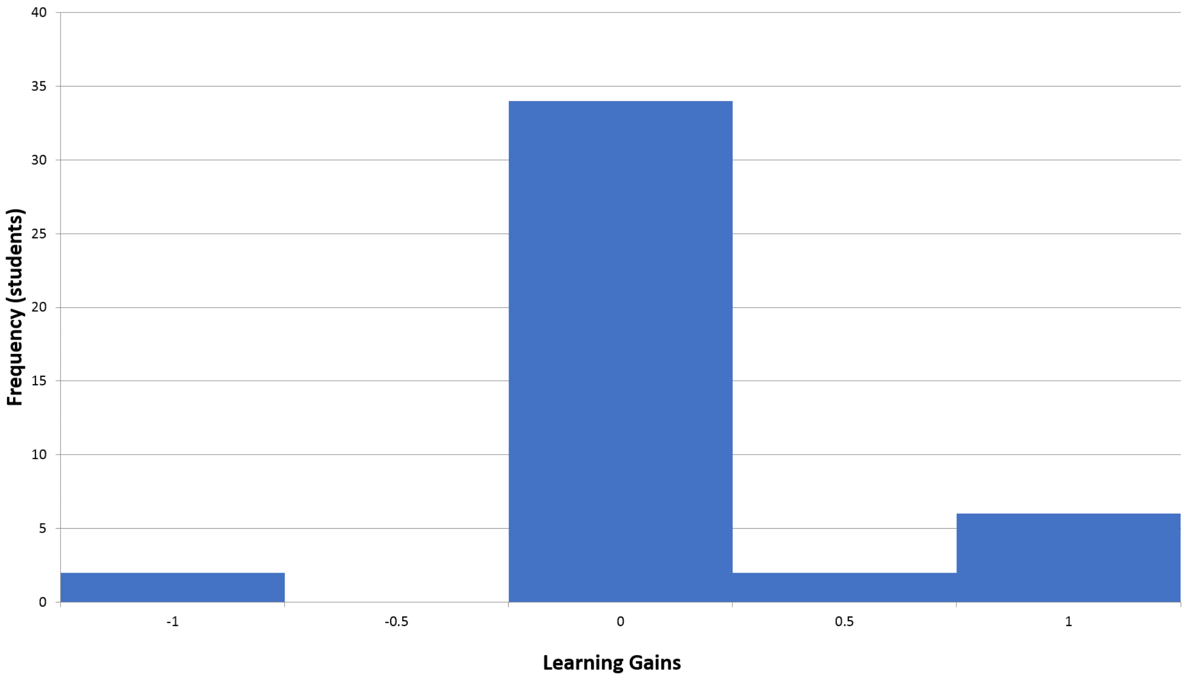

FIGURE 4.1: Learning gains for observational sketching (Q1)

4.3.2 Annotated Sketch Content (Q1)

The average learning gain for annotated sketch content (Q1) was (0.08 ± 0.08). Nineteen students scored the same in both the first and second in-class exercises (i.e., learning gains of 0) (Figure 4.2).

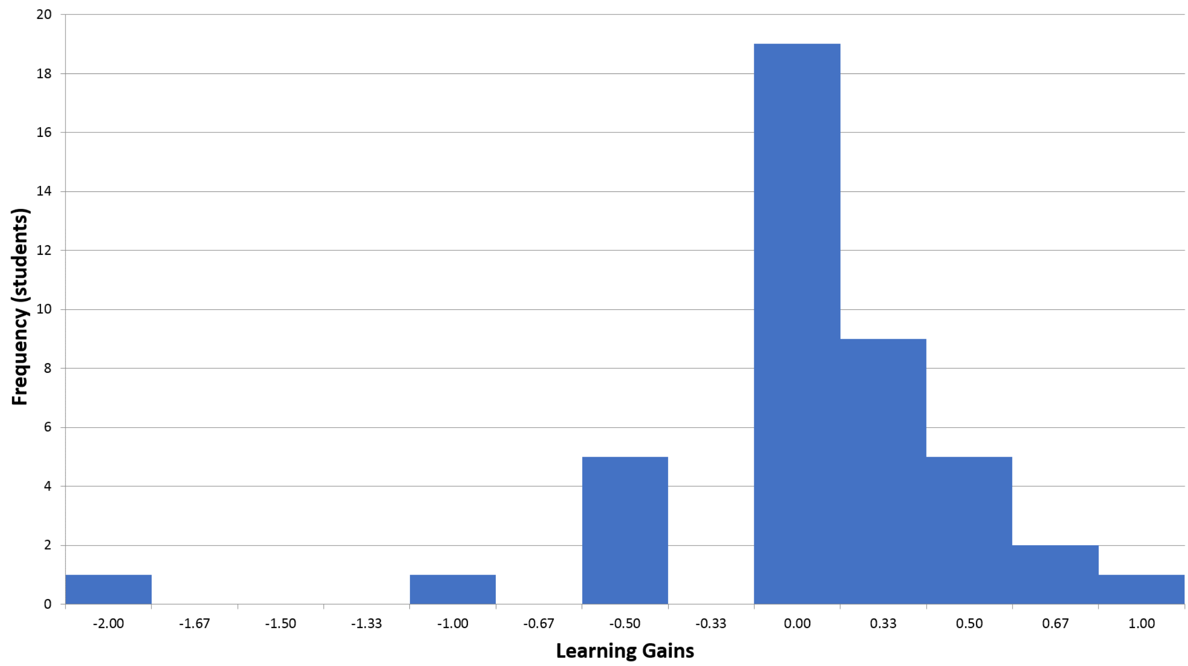

FIGURE 4.2: Learning gains for annotated sketch content (Q1)

4.3.3 Annotated Geological Content (Q1)

The average learning gain for annotated geological content (Q1) was 0.18 ± 0.06 (Figure 4.3). The range of first in-class exercise scores were diverse (20 percent to 80 percent) (Figure 4.3).

4.3.4 Total Annotation

The learning gains data for annotated sketch content and annotated geological content are combined to produce an average learning gain for total annotation in Q1. The average learning gain for total annotation was 0.18 ± 0.05 (Figure 4.4). The in-class exercise scores were diverse (15 percent to 69 percent), with no clear relationship with learning gain (Figure 4.4).

4.3.5 Interpretive Sketching in Side-View (Q3)

The average learning gain for interpretive sketching in side-view (Q3) was 0.26 ± 0.08. Twenty-six students scored the same in both the first and second in-class exercises (i.e., learning gains of 0). Eleven students achieved learning gains of 1 (Figure 4.5).

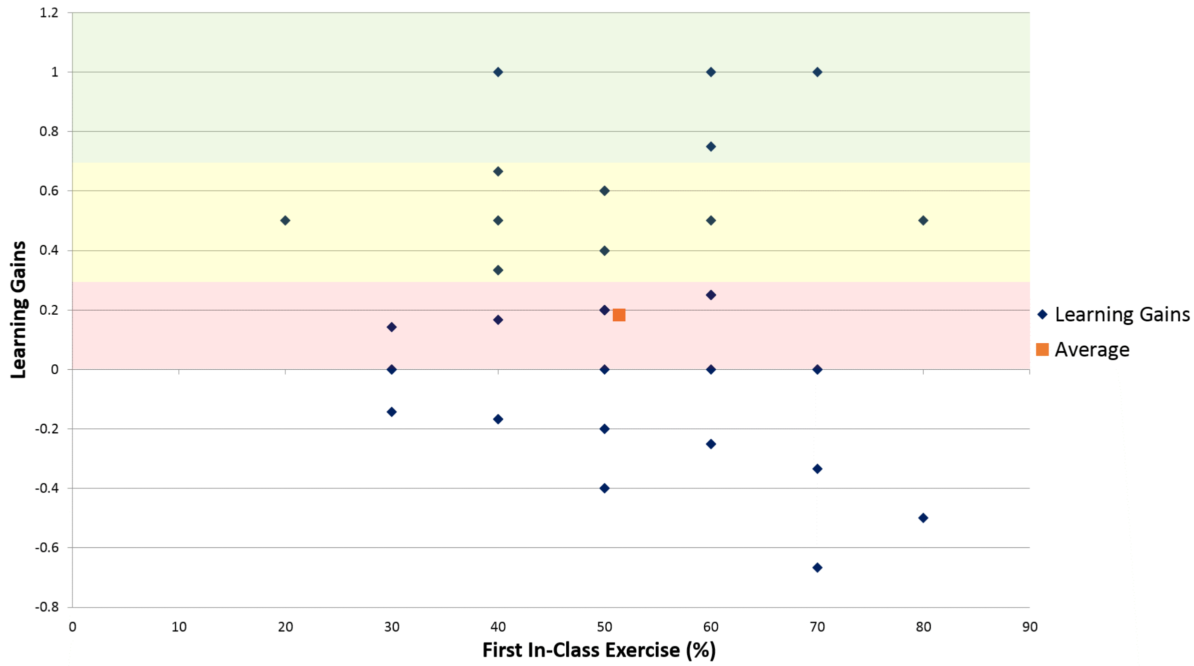

FIGURE 4.3: Learning gains for annotated geological content (Q1). The red section represents low learning gains; the yellow section represents medium learning gains; and the green section represents high learning gains. These sections were based on Hake's metric

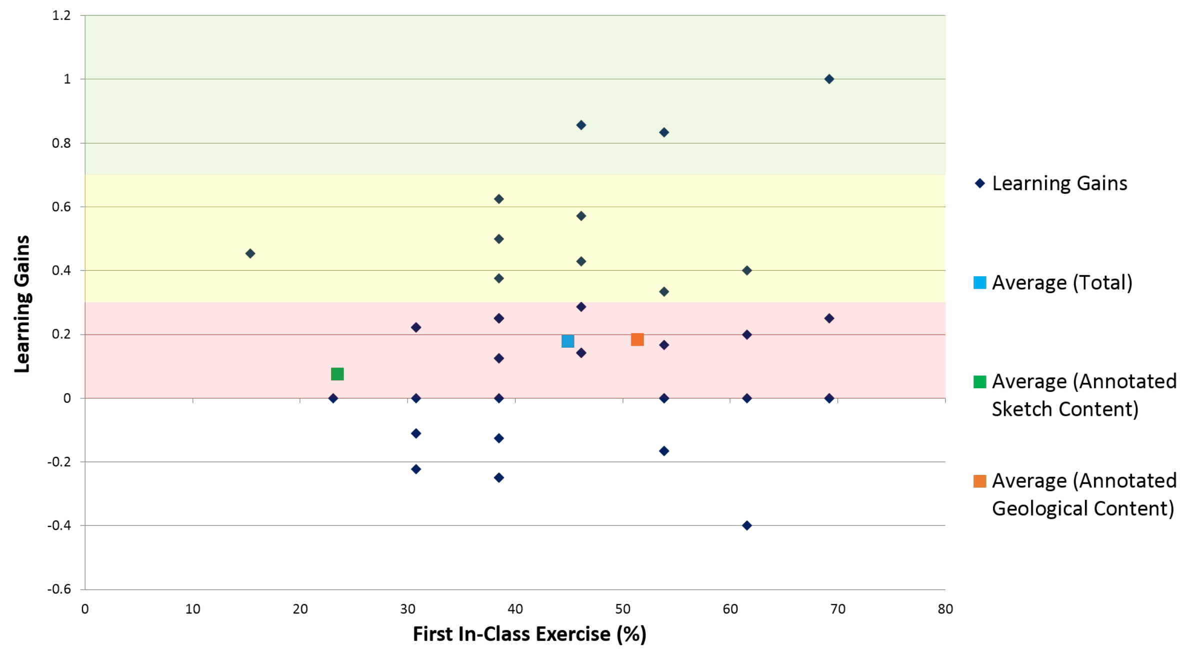

FIGURE 4.4: Learning gains for total annotation. Includes average learning gain for annotated sketch content (Q1) and annotated geological content (Q1). The red section represents low learning gains; the yellow section represents medium learning gains; and the green section represents high learning gains. These sections were based on Hake's metric

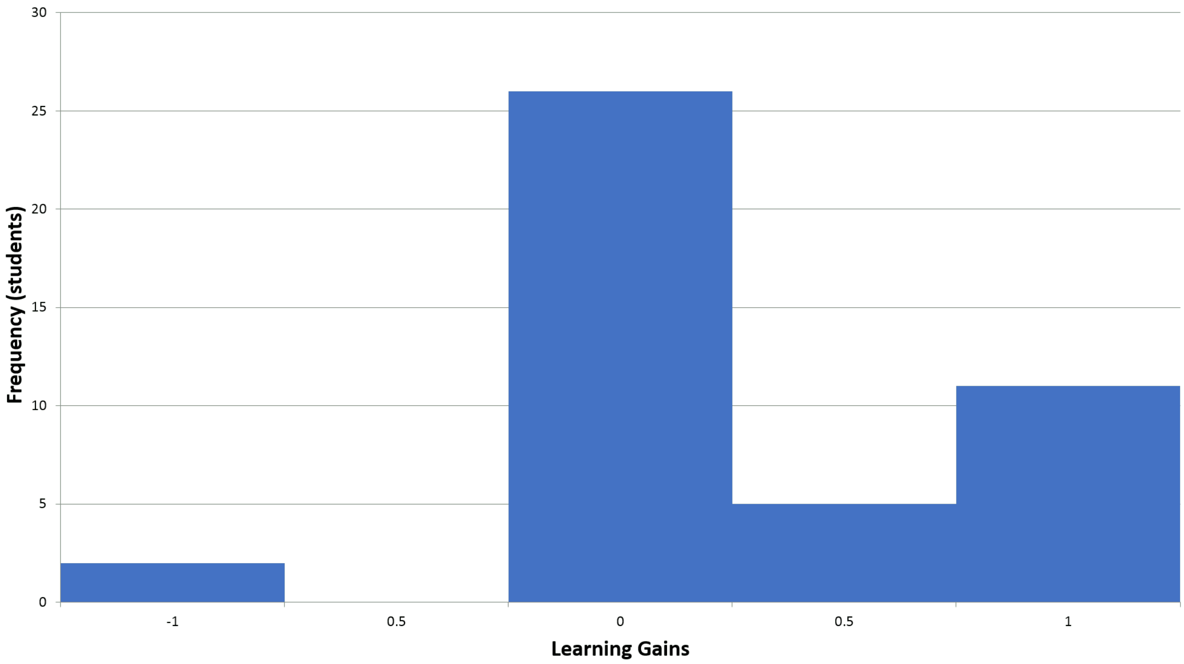

FIGURE 4.5: Learning gains for interpretive sketching in side-view (Q3)

4.3.6 Feature Interpretation in Side-View (Q3)

The average learning gain for feature interpretation in side-view (Q3) was 0.25 ± 0.04 (Figure 4.6). The range of first in-class exercise scores were diverse (0 percent to 62.5 percent), with nine students scoring less than 50 percent (Figure 4.6).

4.3.7 Interpretive Sketching in Map-View (Q4)

The average learning gain for interpretive sketching in map-view (Q4) was 0.50 ± 0.09. Sixteen students scored the same in both the first and second in-class exercises (i.e., learning gains of 0). Twenty-two students achieved learning gains of 1 (Figure 4.7).

4.3.8 Feature Interpretation in Map-View (Q4)

The average learning gain for feature interpretation in map-view (Q4) was 0.34 ± 0.05 (Figure 4.8). The range of first in-class exercise scores were diverse (0 percent to 50 percent) (Figure 4.8).

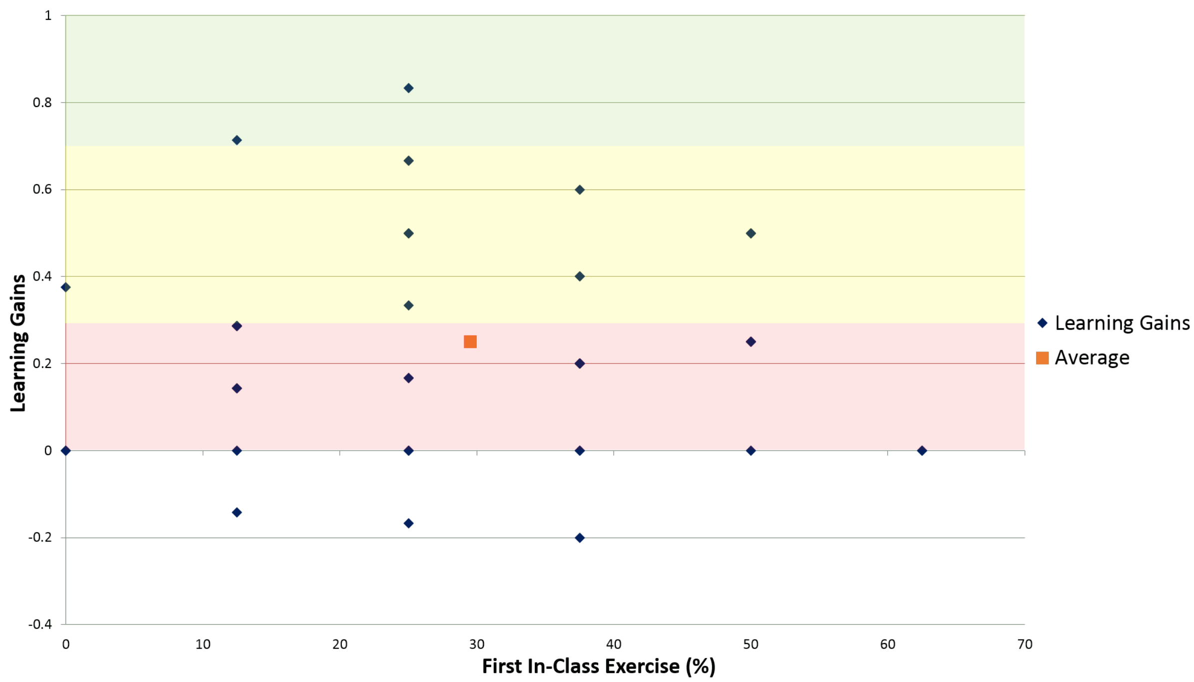

FIGURE 4.6: Learning gains for feature interpretation in side-view (Q3). The red section represents low learning gains; the yellow section represents medium learning gains; and the green section represents high learning gains. These sections were based on Hake's metric

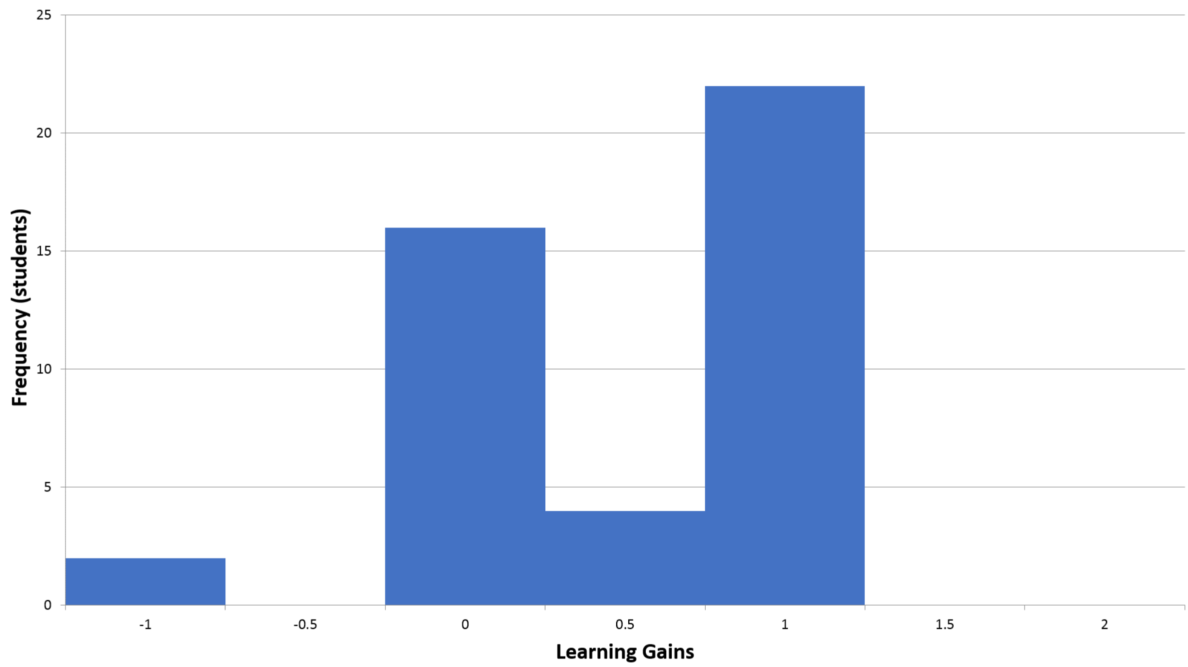

FIGURE 4.7: Learning gains for interpretive sketching in map-view (Q4)

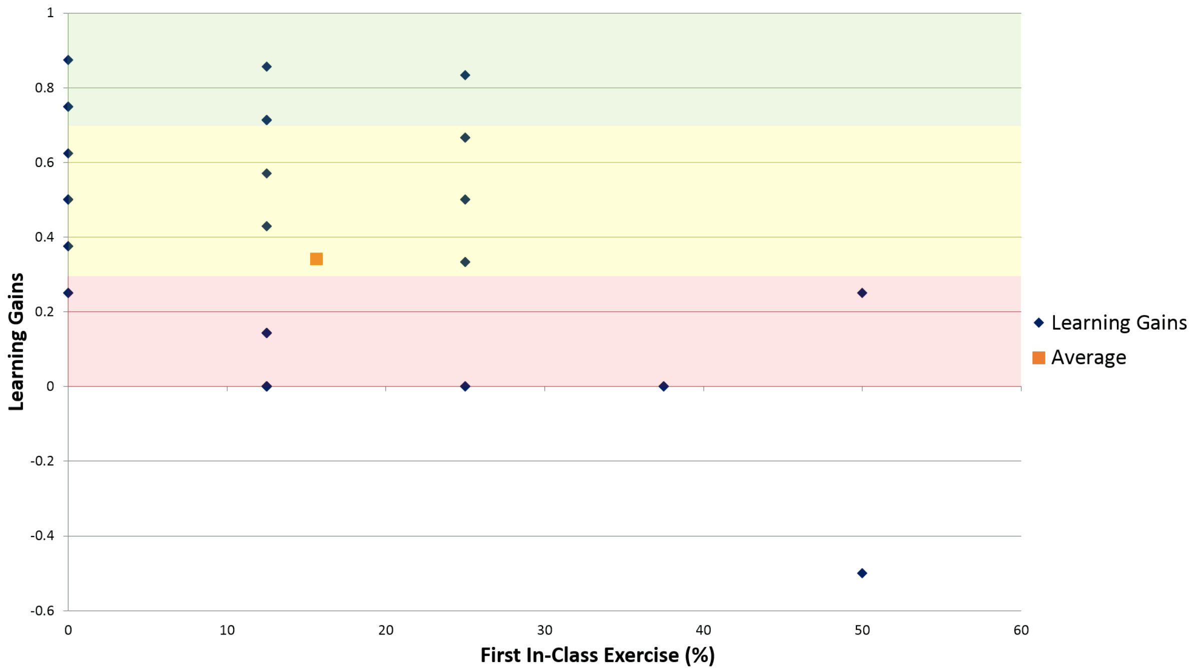

FIGURE 4.8: Learning gains for feature interpretation in map-view (Q4). The red section represents low learning gains; the yellow section represents medium learning gains; and the green section represents high learning gains. These sections were based on Hake's metric

4.3.9 Learning Gains for Total Interpretive Sketching

The learning gains data for interpretive sketching in side-view (Q3) and interpretive sketching in map-view (Q4) are combined to produce an average learning gain for total interpretive sketching. The average learning gain for total interpretive sketching was 0.50 ± 0.09 (Figure 4.9).

4.3.10 Learning Gains for Total Feature Interpretation

The learning gains data for feature interpretation in side-view (Q3) and for feature interpretation in map-view (Q4) are combined to produce an average learning gain for total feature interpretation. The average learning gain for total feature interpretation was 0.31 ± 0.04 (Figure 4.10). The range of first in-class exercise scores were diverse (0 percent to 50 percent) (Figure 4.10).

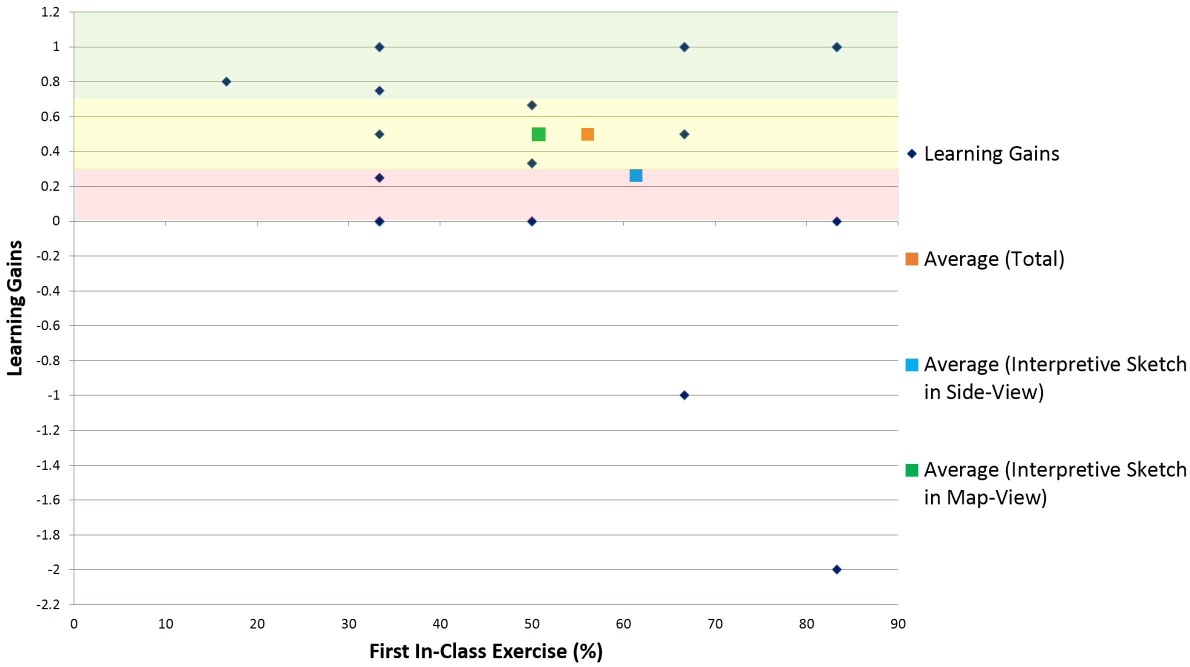

FIGURE 4.9: Learning gains for total interpretive sketching. Includes average learning gain for interpretive sketching in side-view (Q3) and interpretive sketching in map-view (Q4). The red section represents low learning gains; the yellow section represents medium learning gains; and the green section represents high learning gains. These sections were based on Hake's metric

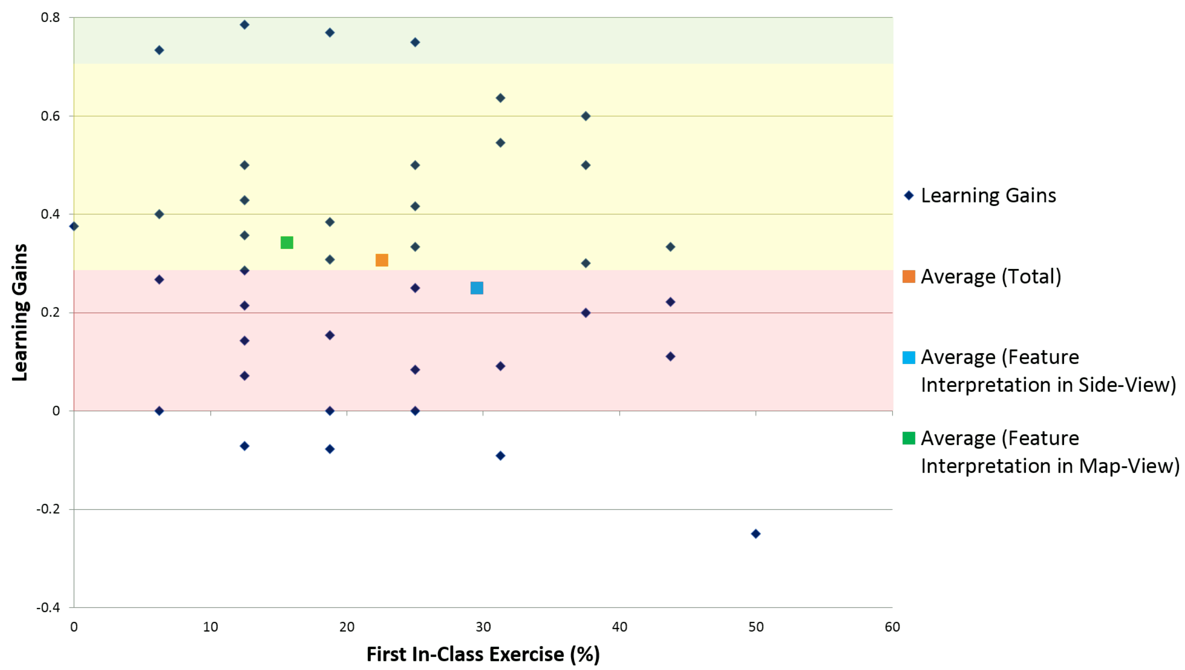

FIGURE 4.10: Learning gains for total feature interpretation. Includes average learning gains for feature interpretation in side-view (Q3) and feature interpretation in map-view (Q4). The red section represents low learning gains; the yellow section represents medium learning gains; and the green section represents high learning gains. These sections were based on Hake's metric

4.4 Feature Analysis for the In-Class Exercise

In addition to calculating the learning gains, the percentage change between the first and second in-class exercise are calculated for the features identified in annotated sketch content (Q1), annotated geological content (Q1), feature interpretation in side-view (Q3) and feature interpretation in map-view (Q4).

The features identified for each rubric part are divided into three categories: 1) features only taught in GEOL336 (within the lava flow module); 2) features only taught in the virtual fieldtrip (GEOL336 IVFT); and 3) features taught in GEOL336 (within the lava flow module) and the GEOL336 IVFT. The features that were only taught in GEOL336 were identified by looking at the GEOL336 PowerPoint slides, the audio from the lectures and the laboratory materials. To identify the features taught in the virtual fieldtrip, the exercises (e.g., multiple-choice questions) and content (e.g., instructional videos and 3D visualisations) were analysed.

The purpose of the feature analysis was to identify what features students observed or interpreted in the Sumner outcrop for the first in-class exercise (that followed the lava flow module) and the second in-class exercise (that followed the virtual fieldtrip). This identifies what features were labelled by students pre- and post virtual fieldtrip.

4.4.1 Feature Analysis for Annotated Sketch Content (Q1)

There was a positive percentage change for scale (30 percent) and direction arrow (2 percent) (Figure 4.11). There was a negative percentage change of 5 percent for non-geological features (Figure 4.11).

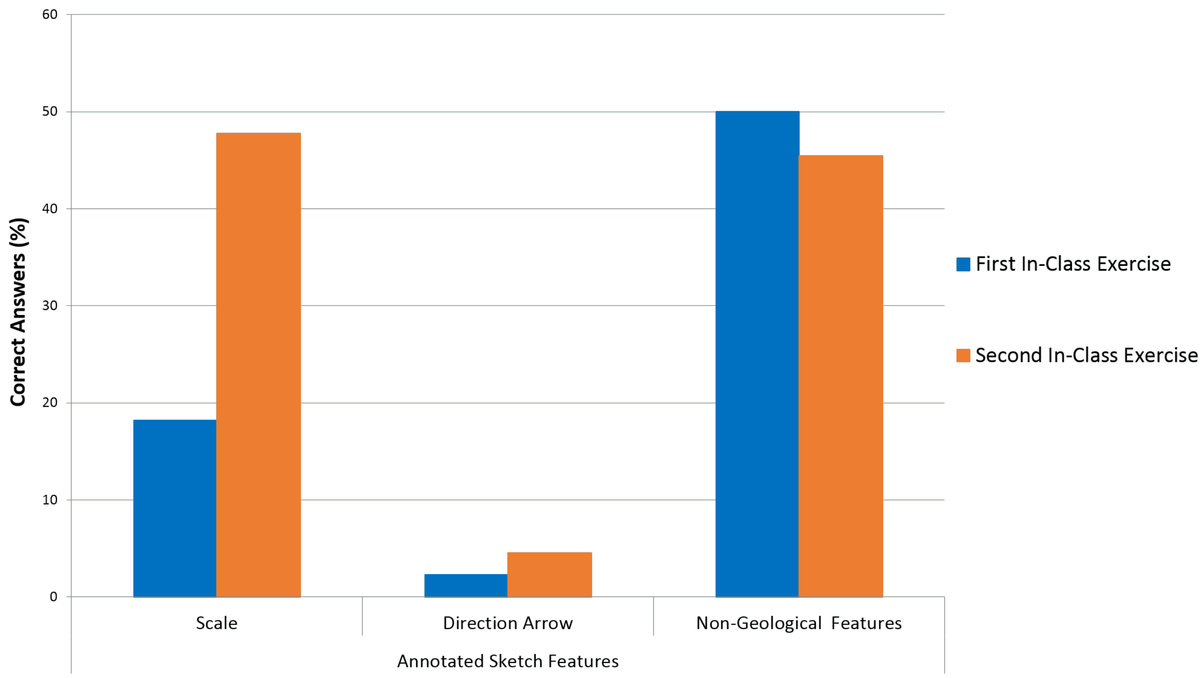

FIGURE 4.11: First and second in-class exercise percentages for annotated sketch content. The correct answer percentage for each feature represents the percentage of students in GEOL336 that correctly identified that feature based on the marking rubric

4.4.2 Feature Analysis for Annotated Geological Content (Q1)

Ash was only taught in the GEOL336 lava flow module and showed a negative percentage change of 11 percent (Figure 4.12). The features only taught in the virtual fieldtrip were multiple layers and sheets. There was a small positive percentage change for multiple layers (2 percent) and there was no percentage change for sheets (Figure 4.12).

For features taught in both the GEOL336 lava flow module and the virtual fieldtrip there was positive percentage change for jointing (2 percent), upper breccia (5 percent), levees (5 percent), channels (36 percent) and lava flows/lava type (33 percent) (Figure 4.12). There was a negative percentage change for lower breccia (2 percent) and colour (20 percent) (Figure 4.12). Overall, for features taught in both the GEOL336 lava flow module and the virtual fieldtrip there was an overall positive percentage change of 8 percent.

Other features that were not in the marking rubric but were awarded extra marks included faulting, grain size, fracture spacing and flow direction. These other geological features showed an overall positive class percentage change of 5 percent.

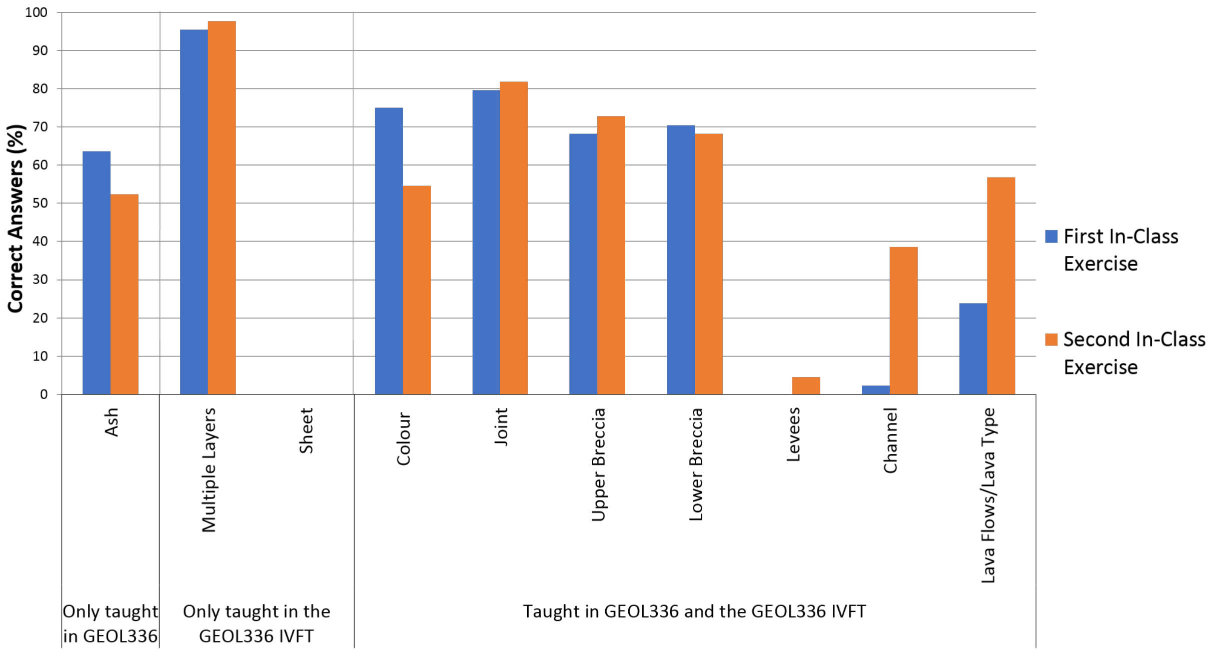

FIGURE 4.12: First and second in-class exercise percentages for annotated geological content. The correct answer percentage for each feature represents the percentage of students in GEOL336 that correctly identified that feature based on the marking rubric

4.4.3 Feature Analysis for Feature Interpretation in Side-View (Q3)

Solid core (11 percent) and toe (43 percent) were only taught in the virtual fieldtrip and showed positive percentage change (Figure 4.13).

Of the features taught in GEOL336 and the virtual fieldtrip scale (27 percent), top breccia (11 percent), base breccia (11 percent) and flow direction (18 percent) showed positive percentage change (Figure 4.13). Joints was the only feature taught in GEOL336 and the virtual fieldtrip that showed a negative percentage change (2 percent). However, joints had the highest class percentage in both the first in-class exercise (80 percent) and the second in-class exercise (82 percent) (Figure 4.13).

Other features that were not in the marking rubric but were awarded extra marks included vesicles, ramp structure, weathering, crystals, joint spacing, erosion, orientation and baked underlying deposit. These other geological features showed an overall positive percentage change of 14 percent (Figure 4.13).

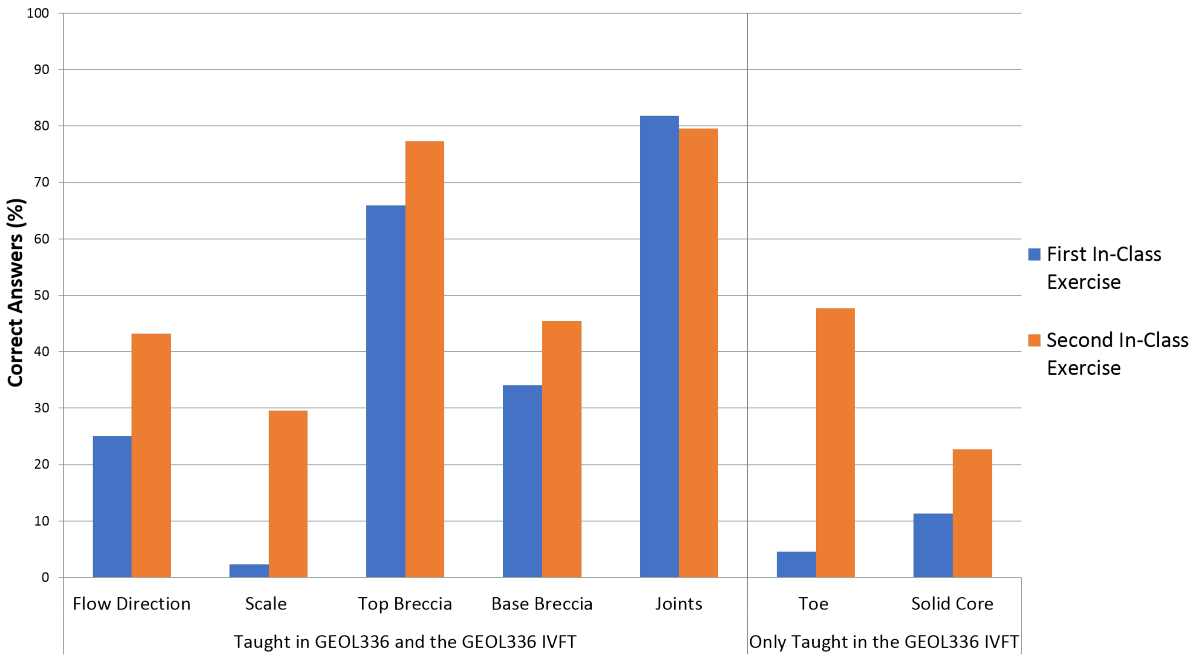

FIGURE 4.13: First and second in-class exercise percentages for feature interpretation in side-view (Q3). The correct answer percentage for each feature represents the percentage of students in GEOL336 that correctly identified that feature based on the marking rubric

4.4.4 Feature Analysis for Feature Interpretation in Map-View (Q4)

Of the features taught in GEOL336 and the virtual fieldtrip scale (36 percent), channel levee (39 percent), channel constrained (36 percent), vent (27 percent) and flow direction (30 percent) showed positive percentage change (Figure 4.14).

Of the features only taught in the virtual fieldtrip side lobes (48 percent) and toe (30 percent) showed positive percentage change (Figure 4.14).

Other features that were not in the marking rubric but were awarded extra marks included ramp features, orientation, vesicles, joint spacing, faulting and volcanic crystals. Other features showed overall positive percentage change of 11 percent.

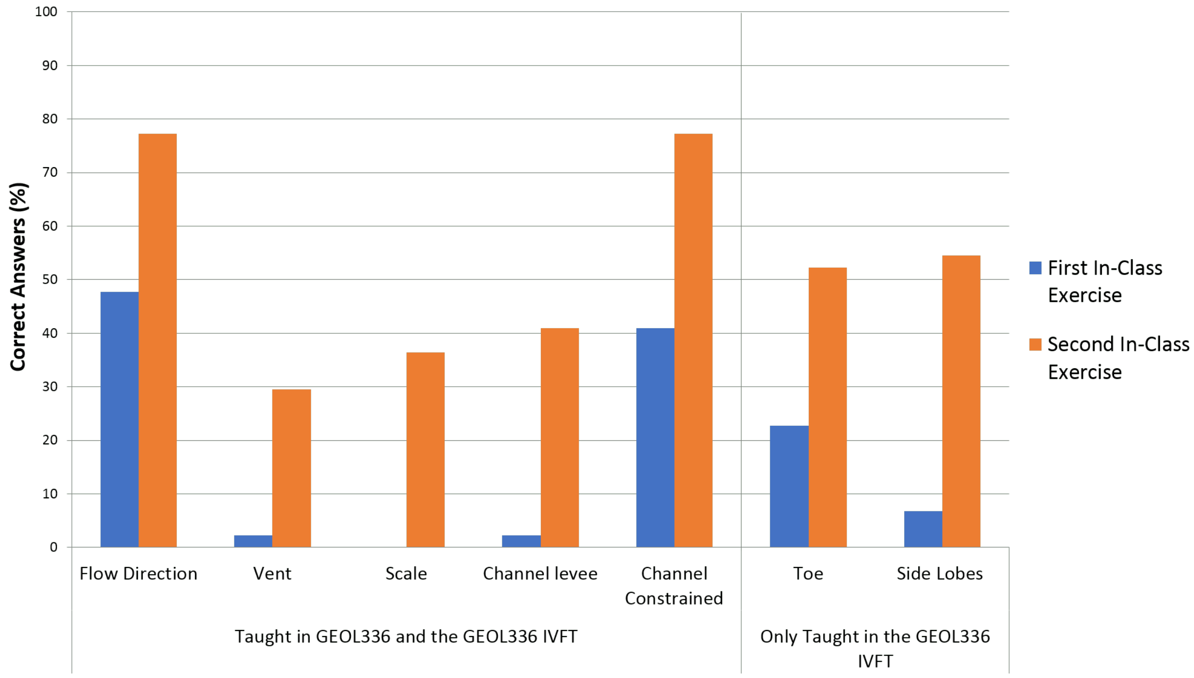

FIGURE 4.14: First and second in-class exercise percentages for feature interpretation in map-view (Q4). The correct answer percentage for each feature represents the percentage of students in GEOL336 that correctly identified that feature based on the marking rubric

4.5 Important Geological Features to a Volcanologist

4.5.1 Quantitative Results

Q2 of the in-class exercise asked students: *"Which of the labels in your sketch are most important to a volcanologist? Why?"*

Student answers for the first in-class exercise included ash (39 percent), columnar jointing (41 percent), lava flows (36 percent), multiple layers/units (25 percent), brecciation (20 percent), colour (23 percent) and blocky (9 percent) (Figure 4.15). Student answers for the second in-class exercise included lava flows (50 percent), columnar jointing (41 percent), brecciation (39 percent), ash (25 percent), colour (16 percent), blocky (5 percent), channels (23 percent), scale/size (23 percent), grain size (21 percent), labelling/annotation (4 percent) and multiple layers/units (16 percent) (Figure 4.15).

Between the first and second in-class exercise, brecciation (18 percent), lava flows (14 percent), channels (23 percent), grain size (21 percent), scale (23 percent) and labelling/annotation (4 percent) showed positive percentage change (Figure 4.15). Columnar jointing showed no change. Layers/units (9 percent), ash (14 percent) and blocky texture (5 percent) showed negative percentage change.

In the first in-class exercise, students annotated 7 geological features 85 times. In the second in-class exercise, students annotated 11 geological features 115 times.

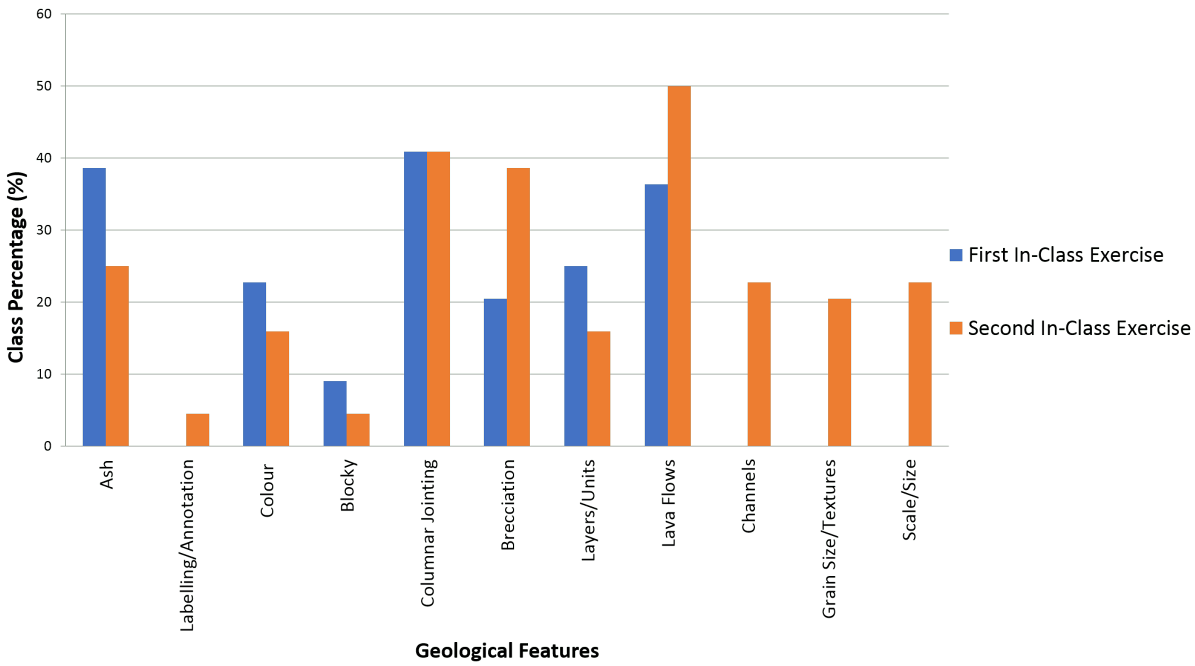

FIGURE 4.15: Geological features included in student answers for the most important features to a volcanologist in the first and second in-class exercise

4.5.2 Qualitative Results

The second part of Q2 asked students why the geological features that they labelled were important to a volcanologist. Twenty-six students answered why the geological features they labelled were important to volcanologists in the first in-class exercise. Thirty-six students answered why the geological features they labelled were important to volcanologists in the second in-class exercise (an extra ten students).

In the first in-class exercise, students stated that the geological features labelled in their sketch helped volcanologists: 1) determine the composition of the lava flow, to distinguish the type of magma chamber (5 percent); 2) determine the number of volcanic events in the outcrop (9 percent); 3) determine the cooling regime (23 percent); 4) identify the volcanic layers to determine the order of events (23 percent); and 5) identify the colour to help distinguish between different volcanic events (5 percent). These are exemplified in the following quotes:

"The columnar jointing indicates cooling and type of eruption and therefore lava flow. The ash deposit shows airfall and different lithology and different eruption, maybe. Brecciated lava indicates the eruption, cooling rate, lava flow and eruption style."

"The various lithologies to understand the past events and when in sequence these occurred. The jointing to understand how the rocks have cooled and crystallised, within this sequence."

In the second in-class exercise students stated that the geological features labelled in their sketch helped volcanologists: 1) determine the type of eruption (27 percent); 2) identify the type of lava flow (32 percent); 3) determine the cooling rate of the lava (18 percent); 4) determine the sequence of events (25 percent); 5) work out the flow direction (11 percent); 6) calculate the scale of the outcrop to determine the eruption size (7 percent); and 7) interpret the magmatic history of the outcrop (9 percent). These are exemplified in the following quotes:

The columnar jointing and brecciating because this shows the features of an a'a' lava flow. The volcanologist would need this information in order to differentiate the type of lava and therefore the eruption style."

"Textures to identify the different types of lava flow. Grainsize, thickness of flow, channel type and structure to understand how the lava fluid mechanics worked and the cooling history. The thickness for the viscosity and magnitude of the erupted lava."

"The different layers and different lithologies could indicate different eruptions."

4.6 Reflective Questionnaire Results

4.6.1 Question One (Q1)

Q1 of the reflective questionnaire asked students: *"What aspects of the Iceland virtual fieldtrip helped you with your interpretation of the outcrop at Sumner? Why?"* The different aspects of the virtual fieldtrip that helped students with their interpretation of the Sumner outcrop can be observed in Figure 4.16.

One of the aspects of the virtual fieldtrip that students stated helped with their interpretation of the Sumner outcrop was learning to identify and interpret volcanic features and structures in the virtual fieldtrip (41 percent of the students) (Figure 4.16). This is exemplified in the following student quote:

"It helped me interpret different parts of the lava flows and the different features that are produced. This has been due to looking at different examples of lava flows and being able to compare them to the Sumner outcrop."

Another aspect of the virtual fieldtrip that students stated helped with their interpretation of the Sumner outcrop were the 3D visualisations (35 percent of the students) (Figure 4.16). As one student wrote:

"The 3D model map views and physically moving around the landscape helps visualise and understand the different views and dimensions of lava flow features as opposed to just viewing the two-dimensional cliff."

Students stated that the instructional videos and 360 videos incorporated in the virtual fieldtrip made interpretation easier (29 percent of the students) (Figure 4.16):

"The use of the 3D videos makes it easy to pan around and look at different features of lava flows such as ropy flow tops, tumuli etc."

Students also noted that learning to understand the differences between the map, side and front views of lava flows helped with their outcrop interpretation (27 percent of the students) (Figure 4.16). These views were presented using a combination of photographs, 360 videos and 3D visualisations.

"In the Iceland virtual fieldtrip, we learnt how to distinguish the different types of lava flows at different view (map, side, and front). This help with interpreting the outcrop at Sumner as we can now work out the type of lava flow from the front view through the textures."

A further aspect of the virtual fieldtrip that students stated helped with their interpretation of the Sumner outcrop was the exemplar sketches with annotations (22 percent of the participants) (Figure 4.16). The following two student quotes support this:

"The sketching aspect of the Iceland virtual fieldtrip helped me with the outcrop interpretation. Being able to look at someone else's sketch and being able to critic it gave me the opportunity to see what made a sketch simple to read and what the key points are to a good sketch."

"The sketches were also helpful as the annotations helped more to visualise the different characteristics from at the views (side, front, and map)."

Students also stated that the 'real-life examples' of lava flows in the virtual fieldtrip helped them with their interpretation of the Sumner outcrop (14 percent of the students) (Figure 4.16). The following student quotes exemplify this:

"Mostly seeing 'in real life' examples from Iceland. This plus the labels gave examples which were applicable to the Sumner example."

"Visually seeing how different volcanic events occurred in real life help me visualise better when seen it in outcrop."

Other aspects of the virtual fieldtrip that students stated helped with their interpretation of the Sumner outcrop included the ability to understand volcanic processes (14 percent), identify lava flows (12 percent), identify volcanic textures (10 percent), determine the differences between lava flows (10 percent) and scale (8 percent) (Figure 4.16).

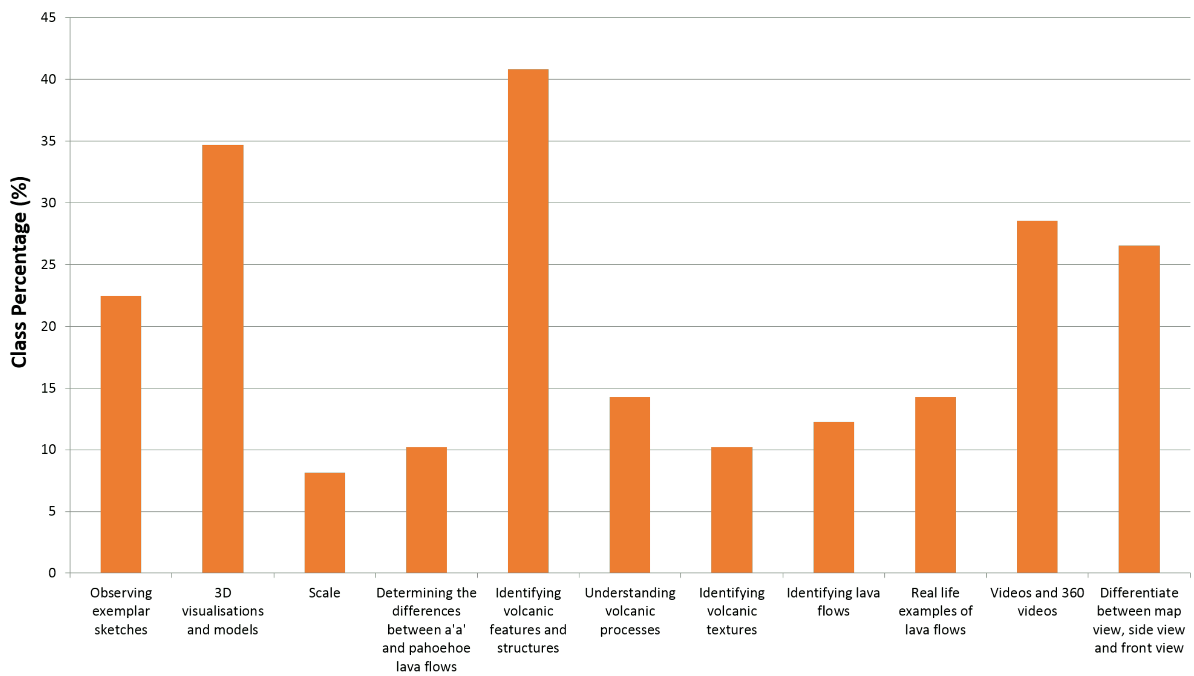

FIGURE 4.16: The aspects of the virtual fieldtrip that helped students interpret the Sumner outcrop

4.6.2 Question Two (Q2)

Q2 of the reflective questionnaire asked students: *"How successful was the Iceland virtual fieldtrip at improving the following (sketching, annotation, motivation and interpretation)? Weight these adding up to 100 percent and explain your reasoning."* Students weighted the virtual fieldtrip as being most successful at improving interpretation with an average student weighting of 37 percent. Annotation (21 percent), sketching (21 percent) and motivation (21 percent) all received the same average student weighting.

Interpretation

Students stated that the virtual fieldtrip helped improve their interpretation of outcrops (Figure 4.17) (29 percent of students). This is exemplified in the following student quotes:

"I can now describe a lava flow and interpret the composition of the magma and the eruption style."

"I think it helped my interpretation the most because I could get my head around the processes."

Students also stated that the 3D visualisations and the instructional videos helped with their interpretation (22 percent of students) (Figure 4.17). This is exemplified in the following student quotes:

"The virtual fieldtrip helped my interpretation, as watching videos of the Iceland area has helped me how to understand these volcanic features better."

"I think it helped my interpretation the most as the exercises and watching the video helped me to understand more on how the magmas behave and their characteristics."

"I found that my interpretation skills improved the most from the fieldtrip. This was due to the different 3D models and Google Earth views of the different parts of the volcano."

Another aspect of the virtual fieldtrip that students stated helped with interpretation were the real-life examples (6 percent of students) (Figure 4.17):

"Seeing real-life examples and explanations from the "comfort" at home/uni allow a more relaxed view of an outcrop/feature."

Students also stated that the virtual fieldtrip was an interactive experience, which helped them with their interpretation (6 percent of students) (Figure 4.17):

"There was a lot of interactive learning when it came to interpretations e.g. watching videos and answering questions about outcrops."

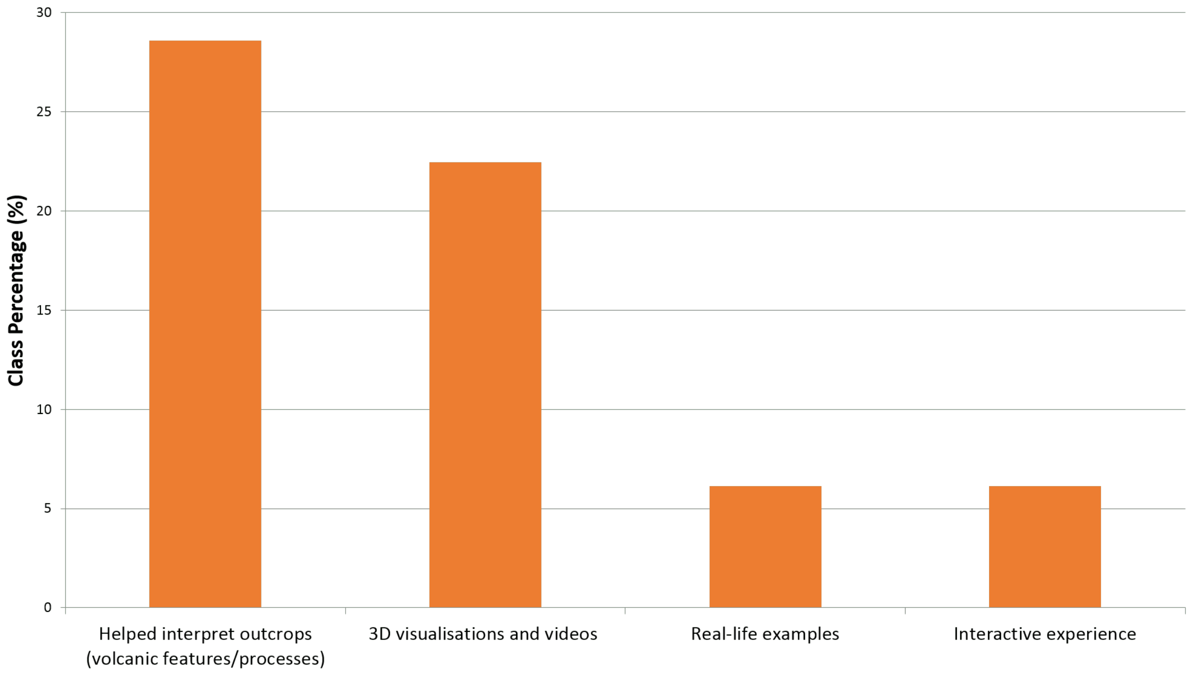

FIGURE 4.17: The aspects of the virtual fieldtrip that students thought were successful at improving their interpretation of the Sumner outcrop

Sketching

Students stated that it was useful to see exemplar sketches in the virtual fieldtrip (37 percent of the students). This is exemplified in the following student quotes:

"The sketches provided showed what we should try make our sketches look like in terms of detail provided and simplicity."

"Was good to look at sketches and be able to criticise them, it really helped with understanding what makes a good diagram/drawing which I can include in mine to make them more reliable and detailed."

However, some students stated that no sketching was practiced in the virtual fieldtrip; therefore, the virtual fieldtrip was not successful at improving sketching (10 percent of the students):

"I improved the least on sketching. This was largely due to the fact that I never needed to sketch anything."

Annotation

There was a general consensus amongst students that the exemplar sketches in the virtual fieldtrip were useful to show the importance of accurate and detailed annotation. (27 percent of the students). This is exemplified in the following student quotes:

"I knew annotating was important, but now I know annotation is equally as important as the physical sketch and should be describing exactly what I'm seeing to aid in sketch ambiguities."

"A clearly annotated sketch is really important as it enhances your interpretation of what features mean."

Motivation

One of the common student responses was that the virtual fieldtrip was enjoyable and fun (16 percent of the students) (Figure 4.18). This is exemplified in the following student quotes:

"Motivation was boosted a lot due to the fun nature of the learning and having 1st hand from experts about all the exciting things in Iceland and potential future breakthroughs."

"Was a unique fun way to learn, hasn't been done before with it being interactive as well as a singular exercise. Fun and educational. I've always been quite motivated, but this was great."

Students also found the virtual fieldtrip an interesting experience (16 percent of the students) (Figure 4.18).

"Really interesting topics presented in an engaging + multi-layered way."

"It stimulated my interest in the area making me more motivated to complete the tasks."

Students stated that the 3D visualisations and instructional videos in the virtual fieldtrip made them more motivated (12 percent) (Figure 4.18). This is exemplified in the following two student quotes:

"I found the virtual fieldtrip much more motivating way of learning. Visually having something to look at instead of listening to someone talking made me more engaged."

"The videos and 3D activities did motivate me to keep working on the correct answers."

Students also stated that the virtual fieldtrip generally increased their motivation (7 percent) (Figure 4.18):

"The fieldtrip made me more motivated to do work, than sitting in lectures."

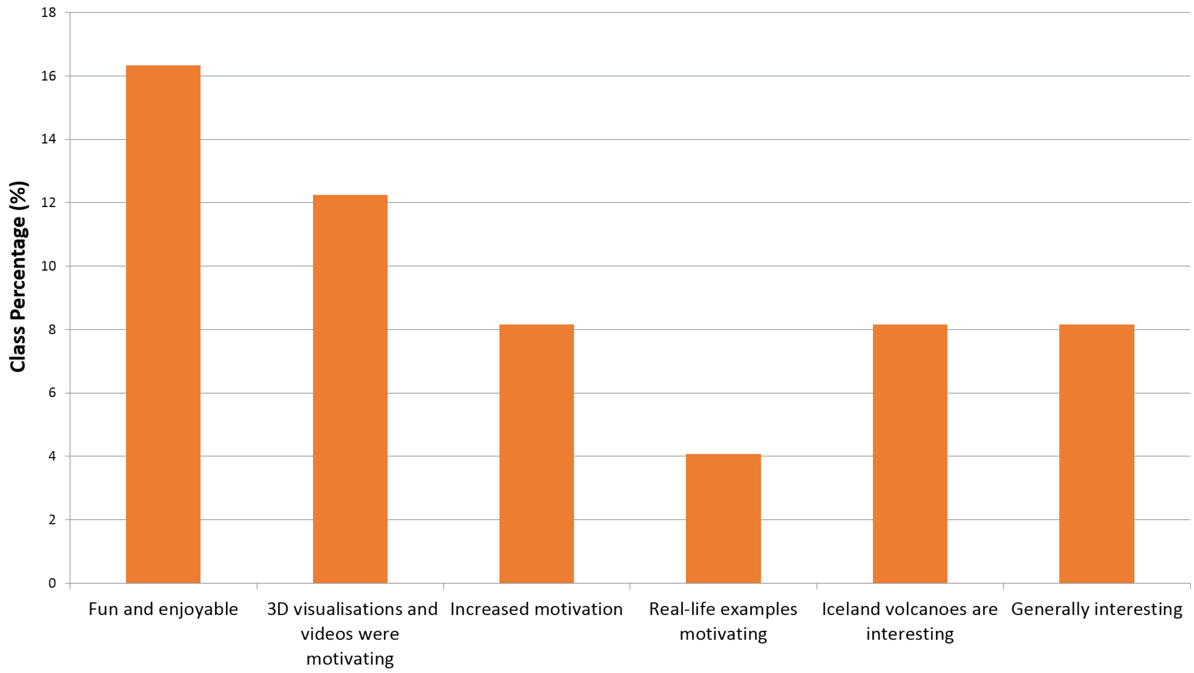

FIGURE 4.18: The aspects of the virtual fieldtrip that students thought were successful at improving motivation

4.6.3 Question Three (Q3)

Q3 of the reflective questionnaire asked students: *"What aspects of the Iceland virtual fieldtrip could be improved? How could these aspects be improved?"* Responses to Q3 indicate that there were some aspects of the virtual fieldtrip that students felt could be improved. These aspects can be observed in Figure 4.19.

One of the aspects that students felt could be improved was Padlet (39 percent of the students) (Figure 4.19):

"Sometimes it was difficult to type on Padlet (lagging a lot), or it wouldn't save what you have written."

There was a consensus amongst these students that it would be better to answer the Padlet questions before being able to see their peers' answers. This is exemplified in the following student quotes:

"I think the Padlet feature could be improved. It would be better if we answered the question individually, then once answered you could then look at other people's answers. This would help people actually think about the questions rather than just agreeing with someone elses answers."

"Do not make the answers of the Padlets visible to everyone before answering the questions. Make them visible only after the question has been answered."

Another aspect of the virtual fieldtrip that students stated could be improved were the technical difficulties (20 percent of the students) (Figure 4.19). Students found that sometimes there were technical difficulties related to slow loading videos. Some of the technical difficulties are identified in the following quotes:

"The only problems that I experienced were technical difficulties. Some videos didn't load (the 360 videos) and it took a long time to fix."

"Sometimes the website was slow, I don't know if this can be improved as it may be due to the amount of people online."

"Long single page web design with lots of videos/3D maps made my computer suuuuper slow to unusable near the end of the page."

To negate these technical difficulties one student stated:

"Long/large webpage did cause issues on some computers – maybe have it divided into separate pages not one continuous page."

A further aspect of the virtual fieldtrip that students said could be improved was to create a save user data for the website (14 percent of students) (Figure 4.19). This is exemplified in the following quote:

"Most recommended: logging in or having your own profile and ability to save answers that you created along the way. This would eliminate the need for PDF submission."

Students also stated that a log-in system for the virtual fieldtrip would be useful (8 percent of students) (Figure 4.19):

"Have a login system, allow multiple attempts, each saved separately: create user accounts."

Some students also thought that practicing more sketching within the virtual fieldtrip may improve sketching (10 percent of students) (Figure 4.19). This is exemplified in the following two student quotes:

"I think that there should be sections where you can practice sketching the outcrop – want help with sketching."

"Require physical sketches from students to improve front/side/map view thinking and annotation. Lots of students are spatial learners and learn by doing, not seeing."

Students also stated that providing context or background material to the virtual fieldtrip would be useful (6 percent) (Figure 4.19):

"Preparation labs/lectures leading up to the fieldtrip so that students have more prior knowledge of Iceland volcanics."

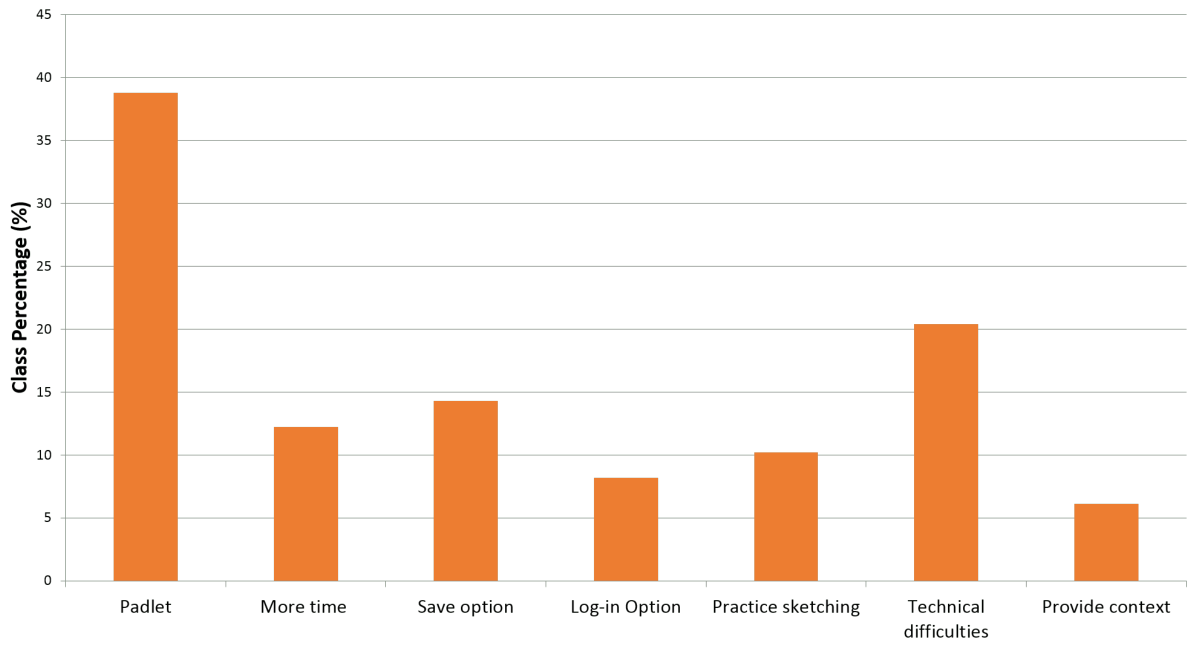

FIGURE 4.19: The aspects of the virtual fieldtrip that students stated could be improved

4.6.4 Question Four (Q4)

Q4 asked students: *"Do you think that the Iceland virtual fieldtrip influenced the amount of effort you put into sketching the Sumner outcrop?"* Forty-nine percent of students agreed that their effort increased following the virtual fieldtrip. This was followed by neutral (28 percent), strongly agreed (21 percent), disagreed (2 percent) and strongly disagreed (0 percent).

The most common student response was that they felt that the virtual fieldtrip enhanced their understanding and interpretation of volcanic features and processes in outcrop (24 percent of students) (Figure 4.20):

"Yes, since I understood how the outcrop formed better (layering, composition etc.). I could write more about the outcrop, describe more processes and annotate better. So yes the amount of effort I put in increased because of the Iceland virtual fieldtrip as I understood more."

"As it allowed me to know more about certain processes (a'a' lava flows, pahoehoe lava flows, mid-ocean ridges etc.), which made me more confident in sketching the outcrop."

Students also stated that the exemplar sketches within the virtual fieldtrip helped their sketching (12 percent of students) (Figure 4.20). One student stated that improvements in these areas improved their effort put into sketching lava flows:

"As the sketches on the fieldtrip help you realise that the drawing can be quite simple and with good annotations. So knowing that I don't have to make the sketch really detail can improve the effort I put in when interpreting outcrop."

"Now that I've been able to see sketches of outcrops on the trip, and know more info about lava flows etc., it felt easier to draw the images/sketches."

Some students related sketching improvements to an increase in effort; however, many students didn't state whether the virtual fieldtrip influenced their effort on the Sumner sketch. The following quote exemplifies this:

"It helped me understand the outcrop better as a whole, and therefore I could put more information onto my sketch."

Students also stated that they wanted to apply their newly acquired skills from the virtual fieldtrip (6 percent of students) (Figure 4.20). This is shown in the following quotes:

"I definitely wanted to show I had learnt something."

"Equipped with the knowledge from the virtual fieldtrip, I felt more motivated to annotate as much as possible to show what I had learned."

Students also responded by saying that the virtual fieldtrip made them more confident (8 percent of students) and more motivated (6 percent of students) (Figure 4.20):

"Felt like I knew more and was more confident on identifying the features (e.g. tuff cone) on the picture."

Some students stated the virtual fieldtrip didn't affect their effort; however, it did improve their skills and knowledge (6 percent of the students) (Figure 4.20):

"I don't think that my amount of effort changed but I believe that the quality of my sketching and interpretation changed to the better after the virtual fieldtrip."

Students also stated that it helped them label and annotate their sketch more (4 percent of students), and that it made them more engaged (2 percent of students).

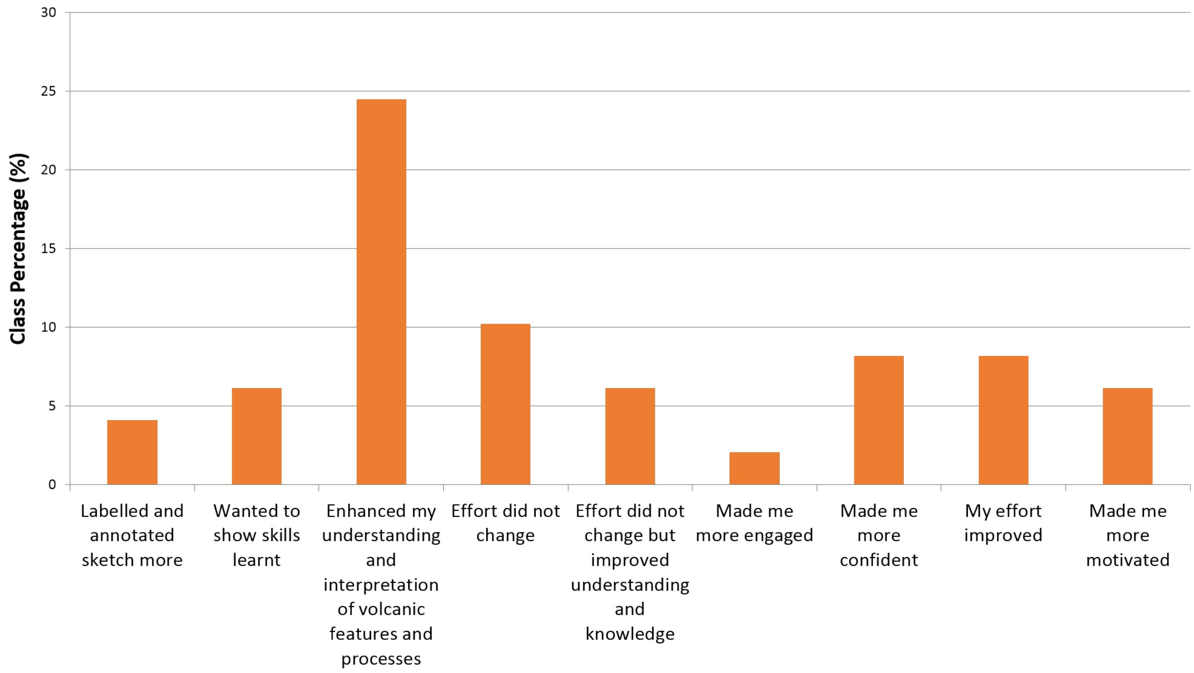

FIGURE 4.20: Student responses on whether the virtual fieldtrip influenced their effort sketching the Sumner outcrop

4.7 Comparing Quantitative and Qualitative Results

The quantitative and qualitative data are compared by matching the student weightings given to sketching, annotation, interpretation and motivation in Q2 of the reflective questionnaire (for each student the weightings are categorised in order from most improved through to least improved), with the equivalent learning gains from the in-class exercise results (e.g., matching the students who weighted interpretation as the most improved factor in the reflective questionnaire, with the learning gains for interpretation from the in-class exercise with the same students). These results are used to determine whether student perceptions of what they thought improved in the reflective questionnaire was what actually improved in the in-class exercise.

The weighting given to sketching is compared with observational sketching and total interpretive sketching. The weighting given to annotation is compared with total annotation. The weighting given to interpretation is compared with total interpretive sketching and total feature interpretation. The weighting given to motivation is compared with observational sketching, total annotation, total interpretive sketching and total feature interpretation.

4.7.1 Sketching

Six students weighted sketching as the most improved (or equal most improved) area following the virtual fieldtrip. These six students scored an average learning gain of 0.08 ± 0.08 for observational sketching and 0.33 ± 0.50 for total interpretive sketching.

Twenty-five students weighted sketching as the least improved (or equal least improved) area following the virtual fieldtrip. These twenty-five students scored an average learning gain of 0.16 ± 0.09 for observational sketching and 0.53 ± 0.09 for total interpretive sketching.

4.7.2 Annotation

Four students weighted annotation as the most improved (or equal most improved) area following the virtual fieldtrip. These four students scored an average learning gain of 0.18 ± 0.16 for total annotation.

A total of twenty students weighted annotation as the least improved (or equal least improved) area following the virtual fieldtrip. These twenty students scored an average learning gain of 0.21 ± 0.07 for total annotation.

4.7.3 Interpretation

Twenty-seven students weighted interpretation as the most improved (or equal most improved) area following the virtual fieldtrip. These twenty-seven students scored an average learning gain of 0.50 ± 0.10 for total interpretive sketching and 0.28 ± 0.04 for total feature interpretation.

A total of three students weighted interpretation as the least improved (or equal least improved) area following the virtual fieldtrip. These three students scored an average learning gain of 0.00 ± 1.00 for total interpretive sketching and 0.27 ± 0.09 for total feature interpretation.

4.7.4 Motivation

Eight students weighted motivation as the most improved (or equal most improved) area following the virtual fieldtrip. These eight students scored an average learning gain of 0.13 ± 0.13 for observational sketching, 0.22 ± 0.13 for total annotation, 0.59 ± 0.12 for total interpretive sketching and 0.26 ± 0.11 for total feature interpretation.

Seventeen students weighted motivation as the least improved (or equal least improved) area following the virtual fieldtrip. These seventeen students scored an average learning gain of 0.18 ± 0.12 for observational sketching, 0.17 ± 0.07 for total annotation, 0.25 ± 0.19 for total interpretive sketching and 0.32 ± 0.06 for total feature interpretation.

4.8 Summary of Results

- Positive learning gains were measured for observational sketching (0.11 ± 0.06), annotated sketch content (0.08 ± 0.08), annotated geological content (0.18 ± 0.06), interpretive sketching in side-view (0.26 ± 0.08), feature interpretation in side-view (0.25 ± 0.04), interpretive sketching in map-view (0.50 ± 0.09) and feature interpretation in map-view (0.34 ± 0.05).
- There was positive percentage change for all of the features taught in GEOL336 (within the lava flow module) and the virtual fieldtrip, except colour, lower breccia and joints. There was negative percentage change for ash (the geological feature only taught in GEOL336 (within the lava flow module). Positive percentage change was recorded for all of the geological features that were only taught in the virtual fieldtrip, except sheets which showed no change.
- Students listed more geological features as important to a volcanologist in the second in-class exercise, and provided more reasons as to why these features were important to a volcanologist.
- Students weighted interpretation as the most improved factor following the virtual fieldtrip. Students stated that the 3D visualisations, instructional videos and exemplar sketches were aspects of the virtual fieldtrip that aided their interpretation. Students also stated that the exemplar sketches helped their in-class exercise sketching and annotation.
- Students who weighted interpretation as the most improved area following the virtual fieldtrip scored higher learning gains for interpretation, compared to the students who weighted interpretation as the least improved area. Students who weighted sketching and annotation as the most improved area following the virtual fieldtrip scored lower learning gains for sketching and annotation, relative to the students who weighted sketching and annotation as the least improved area.

- Students stated that the virtual fieldtrip was an enjoyable, interesting and motivating experience. Students who believed their motivation improved the most following the virtual fieldtrip improved in interpretive sketching and total annotation, relative to the students who believed their motivation improved the least. Students who believed their motivation improved the least following the virtual fieldtrip performed better at observational sketching and total feature interpretation.

Chapter 5

Discussion

The in-class exercise and reflective questionnaire results indicate that the virtual fieldtrip was an effective tool to aid student sketching and interpretation of lava flows. The results presented in Chapter 4 are discussed in this chapter to determine which aspects of the virtual fieldtrip were effective and why. Together, the combination of the quantitative and qualitative data provides a complementary and robust set of results.

5.1 Observational Sketching and Annotation

Observational Sketching

The in-class exercise results indicate that the virtual fieldtrip was an effective tool to aid observational sketching. The average learning gain for observational sketching (Q1) was 0.11 ± 0.06. One possible reason for these gains in observational sketching was the focus on exemplar sketches in the virtual fieldtrip. Consistent with this, students stated in the reflective questionnaire:

"It was good to observe a range of exemplar sketches in the GEOL336 Iceland virtual fieldtrip, as it helped see the level of detail required in the sketches."

Although students achieved positive learning gains for observational sketching, these gains were low based on Hake's metric. One possible reason for the relatively low gains was that thirty-two out of forty-four students achieved no learning gains for observational sketching (students achieved the same score in both the first and second in-class exercise). This may have been caused by the restriction of range for observational sketching in the marking rubric (potential marks out of three, with no partial credit). This meant that it was more likely for students to achieve the same score in both the first and second in-class exercise.

Another possible reason for the relatively low learning gains was that no observational sketching was practiced in the virtual fieldtrip. This is reflected in the statements of five students in the reflective questionnaire, who stated that they did not practice sketching in the virtual fieldtrip:

"I improved the least on sketching. This was largely due to the fact that I never needed to sketch anything."

It is interesting to note that these five students scored full marks in observational sketching for both the first and second in-class exercise resulting in no learning gains. These students were more likely to achieve the same or lower score in the second in-class exercise as they couldn't improve their score in the observational sketch.

Annotation

The in-class exercise and reflective questionnaire results indicate that the virtual fieldtrip was an effective tool to aid student annotation. Positive learning gains were measured for total annotation (0.18 ± 0.05), annotated sketch content (0.08 ± 0.08) and annotated geological content (0.18 ± 0.06). Two of these learning gains (with the exception of annotated sketch content) were higher than observational sketching.

The exemplar sketches in the virtual fieldtrip were designed to improve both student sketching and annotation. The exemplar sketches with annotations may have shown students the importance of accurate and detailed annotations. This is supported by the following student statement:

"It was good to see exemplar sketches with annotations as they showed the importance of accurate and detailed annotation."

The features in annotated geological content that were taught in GEOL336 (within the lava flow module) and the virtual fieldtrip all showed positive change, except lower breccia (-2 percent). This implies that the geological features taught in GEOL336 (within the lava flow module) and reinforced in the virtual fieldtrip were more likely to be included in student annotations within the observational sketch in the second in-class exercise. The features that showed the highest positive percentage change were scale, channels and lava flows/lava types. These features were included in multiple exercises within each location of the virtual fieldtrip, indicating that the virtual fieldtrip was most effective at reinforcing these particular features. This is supported by other studies, which show that students retain knowledge through content reinforcement in online learning environments (e.g., Chen, Yeh, and Chang, 2016; Grechus and

Brown, 2000). These online activities can provide reinforcement to traditional class lectures (Rivera, 2016).

Although most of the features showed positive percentage change, the low to medium first in-class exercise scores (15-69 percent) indicate that students struggled to annotate the sketch and geological features. One possible reason for this may have been that some of the geological features (e.g., multiple layers and sheets) were not explicitly taught in the GEOL336 lava flow module (these features were explicitly taught in the virtual fieldtrip). This meant that these features weren't reinforced in the virtual fieldtrip, but were taught for the first time in the virtual fieldtrip. This may have contributed to the low first in-class exercise score; however, these features did not show significant change following the virtual fieldtrip (multiple layers showed a positive change of 2 percent and sheets showed no percentage change). To remediate this, these geological features need to be explicitly introduced earlier in the GEOL336 curriculum.

The average learning gain for annotated geological content plotted in the low gains category, based on Hake's metric. One of the reasons for these relatively low gains could be that ash (Figure 4.12) was not taught in the virtual fieldtrip (ash showed a negative change of 11 percent). This implies that geological features which were not taught and reinforced in the virtual fieldtrip were less likely to be included in the annotations within the observational sketch. Ash was a geological concept taught in GEOL336 (within the lava flow module), which was not integrated into the virtual fieldtrip. Therefore, one of the cognitive demands required of virtual fieldtrips (integrating prior knowledge) was not met, resulting in ash showing a negative percentage change. This could be remediated by including ash in multiple exercises in the next iteration of the virtual fieldtrip.

Observational Sketching and Annotation

As noted in Chapter 3, observational sketching and annotation is practiced in prerequisite geology courses at the University of Canterbury (Dohaney et al., 2015); therefore, it is likely that the GEOL336 students were competent at observational sketching and annotation prior to completing the first in-class exercise. This is confirmed by the average GEOL336 percentage for observational sketching in the first in-class exercise (85 percent).

It should be noted that observational sketching and annotation were not design properties of the virtual fieldtrip and were not included as virtual fieldtrip exercises. Other studies have implemented sketching exercises within virtual fieldtrips to improve sketching and visuo-spatial skills (Dolphin et al., 2019). Learning gains have been observed in studies where more sketching activities have been implemented (Cooper et al., 2017; Dolphin et al., 2019); however, other studies have shown that there is no relationship between completing more sketches and higher learning gains (Gagnier et al., 2017). Based on these studies, it appears that sketching should be practiced to either improve sketching or improve the understanding of the object being sketched. Nevertheless, gains were observed for observational sketching and annotation in this research. This can partially be attributed to the 3D visualisations, exemplar sketches and the reinforcement of course content.

5.2 Interpretation

5.2.1 Interpretive Sketching in Side-View and Map-View

The in-class exercise and reflective questionnaire results indicate that the virtual fieldtrip was an effective tool to aid interpretive sketching in both side-view and map-view. Positive learning gains were measured for total interpretive sketching (0.50 ± 0.09), interpretive sketching in side-view (0.26 ± 0.08) and interpretive sketching in map-view (0.50 ± 0.09). These gains were significantly higher than the gains measured for observational sketching and annotation. This is reflected in the improvement of individual student interpretive sketches in both side-view (Figure 5.1) and map-view (Figure 5.2).

A possible reason for the higher learning gains for interpretive sketching may have been that the exemplar sketches in the virtual fieldtrip may have familiarised the students with different sketching perspectives. Students stated in the reflective questionnaire that:

"The fieldtrip showed us what cross-sections of a'a' flows looked like – previously we were only familiar with a student conceptual model."

"Was cool to see how different people sketch - provide different perspectives."

"The sketches were also helpful as the annotations helped more to visualise the different characteristics from at the views (side, front, and map)."

A further reason for the higher learning gains for interpretive sketching may have been that students viewed lava flows from map-view using the interactive 3D visualisations at Krafla, where a high resolution SfM was available to be manipulated to provide a variety of perspectives. Immersive, interactive visualisations of geology models can give the user new insights during interpretation (R. R. Jones et al., 2009). Additionally, the 360 instructional videos showed views of the lava flows at Heimaey from map-view and side-view. Students commented on these features in the reflective questionnaire:

"The 3D model map views and physically moving around the landscape helps visualise and understand the different views and dimensions of lava flow features as opposed to just viewing the two-dimensional cliff."

"The field videos looking at how lava flows consist of different properties depending on where your looking (e.g. cross-section, front-lobe, a'a' vs pahoehoe). It made interpreting what Sumner outcrop may look like in cross-section."

On average, students scored higher learning gains for interpretive sketching in map-view compared to interpretive sketching in side-view. This may have been due to an example of an interpretive sketch in map-view being displayed at the Heimaey location in the virtual fieldtrip, familiarising students with an interpretive sketch in map-view.

For interpretive sketching in side-view, twenty-six students achieved zero learning gains and eleven students achieved learning gains of one. For interpretive sketching in map-view, fifteen students achieved zero learning gains and twenty students achieved a learning gain of one. A possible reason for students scoring the same in the first and second in-class exercise is the restriction of range for interpretive sketching in the marking rubric (potential marks out of three, with no partial marks). This makes it more likely for students to score the same interpretive sketching grade in both in-class exercises.

Students achieved higher learning gains for interpretive sketching than for observational sketching. The interpretive sketching required a higher-level of learning ('analysis level') than the observational sketching ('comprehension level'). For the observational sketch in cross-section (Q1), students had to identify the key geological features and process in the Sumner outcrop. For the interpretive sketching students needed to interpret the possible geological features and processes that may be present in side-view and map-view. Students weighted interpretation as the most improved factor following the virtual fieldtrip:

"I think it helped my interpretation the most because I could get my head around the processes."

"Interpretation was most positively impacted as the 3D, 360 videos and complementary commentary educated me in how features were formed and why behaviours were seen."

Interpretation is a high-level learning skill based on Bloom's taxonomy (Bloom, 1956). Based on the higher learning gains for interpretive sketching than observational sketching and annotation, it can be concluded that the virtual fieldtrip was more effective at scaffolding students to a higher-level of learning, where they were more capable of interpretation. The virtual fieldtrip likely aided student interpretation, but is unlikely to be the sole contributing factor as students were still taught additional GEOL336 content between the first and second in-class exercise.

5.2.2 Feature Interpretation in Side-View and Map-View

The in-class exercise and reflective questionnaire results indicate that the virtual fieldtrip was an effective tool to aid feature interpretation. Total feature interpretation (0.31 $\pm$ 0.04), feature interpretation in side-view (0.25 $\pm$ 0.04) and feature interpretation in map-view (0.34 $\pm$ 0.05) measured positive learning gains. These learning gains were higher than both observational sketching and annotation.

One possible reason for these higher gains were the 3D visualisations and instructional videos in the virtual fieldtrip. Students stated in the reflective questionnaire that:

"The use of the 3D videos makes it easy to pan around and look at different features of lava flows such as ropy flow tops, tumuli etc."

"It helped me to better interpret the outcrop because the fieldtrip looked at a similar situation in 3D by looking at the plan view, front view and side view. It also helped me to better estimate scale and size of different layers."

These technologies were implemented in the virtual fieldtrip to aid the development of spatial skills to improve student interpretation of lava flows. In other studies, 3D visualisations aided student visual penetrative ability and student learning (Giorgis, 2015; McCaffrey et al., 2008). Preppernau and Jenny (2015) showed that students were able to interpret terrain better using 3D maps. These immersive, interactive visualisations of geology models can give students new insights during interpretation (R. R. Jones et al., 2009). The use of the technologies to show different angles, features and dimensions of lava flows may have been a contributing factor to improve student interpretation. This may have aided students in identifying the features found in both a'a' and pahoehoe lava flows from different perspectives:

"In the Iceland virtual fieldtrip, we learnt how to distinguish the different types of lava flows at different views (map, side and front). This helps with interpreting the outcrop at Sumner as we can now work out the type of lava flow from the front-view through textures."

"Understanding the front, side and map view of lava flows in Iceland helped me determine the types of flows and deposits at Sumner."

Students achieved higher gains for feature interpretation in map-view than for feature interpretation in side-view. The 3D visualisations in the virtual fieldtrip were easier to manipulate in map-view, which may have resulted in higher gains. These 3D visualisations allow users the opportunity to engage in geological formations from numerous perspectives (e.g., side-view and map-view) (Giorgis, 2015).

All of the interpreted geological features had a positive percentage change greater than 10 percent (except for joints). This shows that student feature interpretation of lava flows was aided by the virtual fieldtrip. This is reflected in the interpreted geological features annotated on student interpretive sketches in side-view (Figure 5.1) and map-view (Figure 5.2). This implies that the geological features taught in GEOL336 (within the lava flow module) and reinforced in the virtual fieldtrip were more likely to be included in student interpretations in the second in-class exercise (e.g., Chen et al., 2016; Grechus and Brown, 2000).

Although learning gains were relatively high for feature interpretation, students scored low percentages in both the first and second in-class exercise for feature interpretation in side-view (less than or equal to 62 percent) and map-view (less than or equal to 50 percent). These low scores indicate that the students struggled to interpret the geological features in both in-class exercises. A possible reason for these low percentages was the marking rubric. The model answer may have been unrealistic for students to achieve high grades for feature interpretation in the in-class exercise. An interesting point to note is that some students scored 0 percent in the first in-class exercise for feature interpretation in map-view. One reason for this could include a lack of effort, as it was the last question in the in-class exercise and was only worth a fraction of the GEOL336 grade.

A further reason for these low first in-class percentages may be that some of the geological features hadn't been explicitly taught in GEOL336 (within the lava flow module). Solid core, toe flow direction and side lobes were all geological features that were not explicitly taught in the GEOL336 lava flow module. This means that the first time students were taught about these geological features was in the virtual fieldtrip; therefore, these features were not reinforced. This could be the reason why low percentages were scored for these features in the first in-class exercise. However, many of the geological features taught in both the GEOL336 lava flow module and the virtual fieldtrip showed low percentage change (e.g., scale, channel levee, vents and base breccia). Therefore, these geological features may need to be included in more exercises within the virtual fieldtrip.

Interpretation is a high-level learning skill based on Bloom's taxonomy (Bloom, 1956).

Higher learning gains were measured for feature interpretation than both observational sketching and annotation. Therefore, it can be concluded that the virtual field-trip was effective at scaffolding students to a higher-level of learning, where they were more capable of interpretation. However, it was unlikely that the virtual fieldtrip was the sole contributing factor as students continued to be taught in GEOL336 between the first and second in-class exercise.

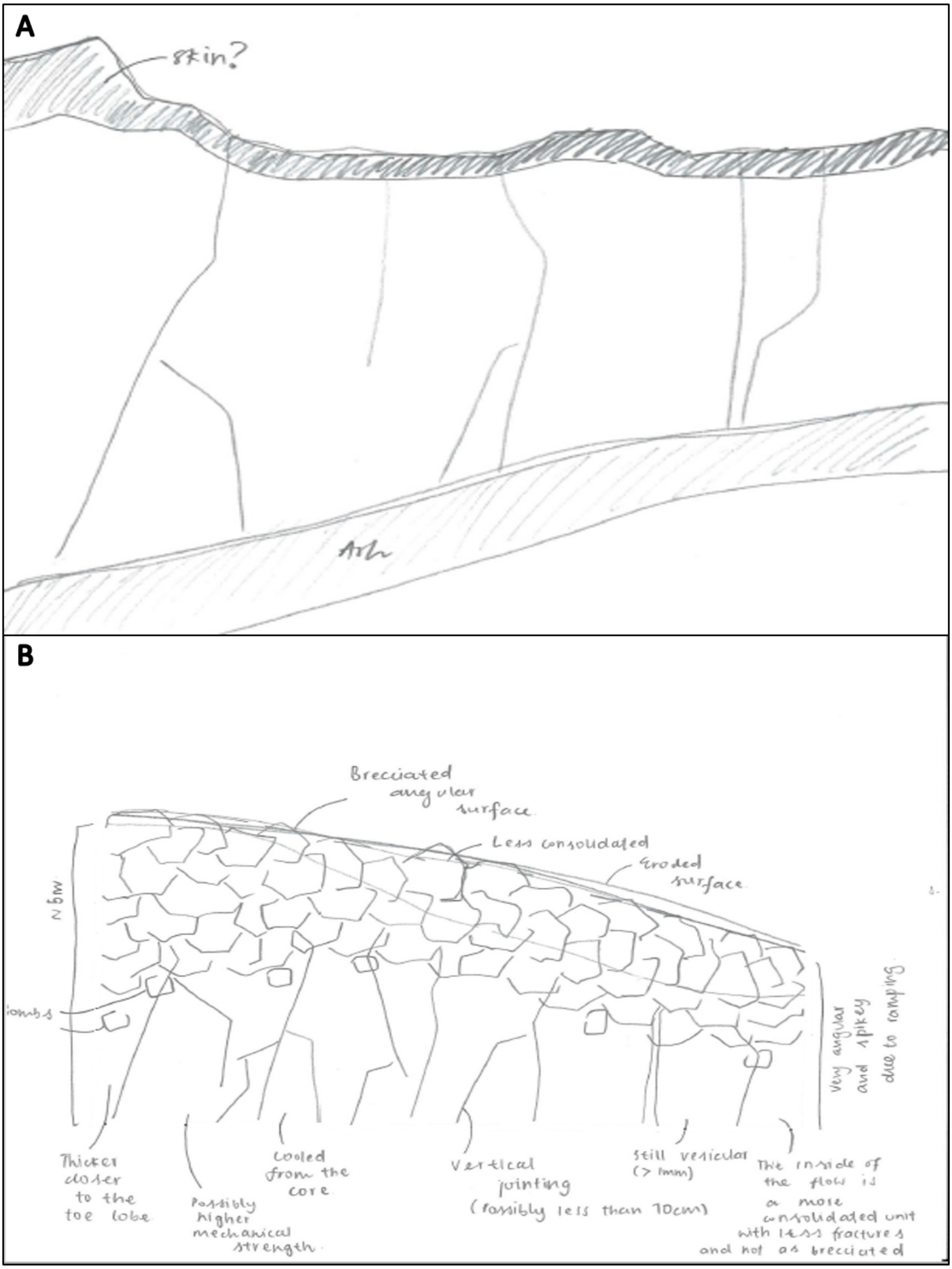

FIGURE 5.1: First and second in-class exercise sketches for Q3. (A) is a student's interpretive sketch in side-view from the first in-class exercise; and (B) is a student's interpretive sketch in side-view from the second in-class exercise

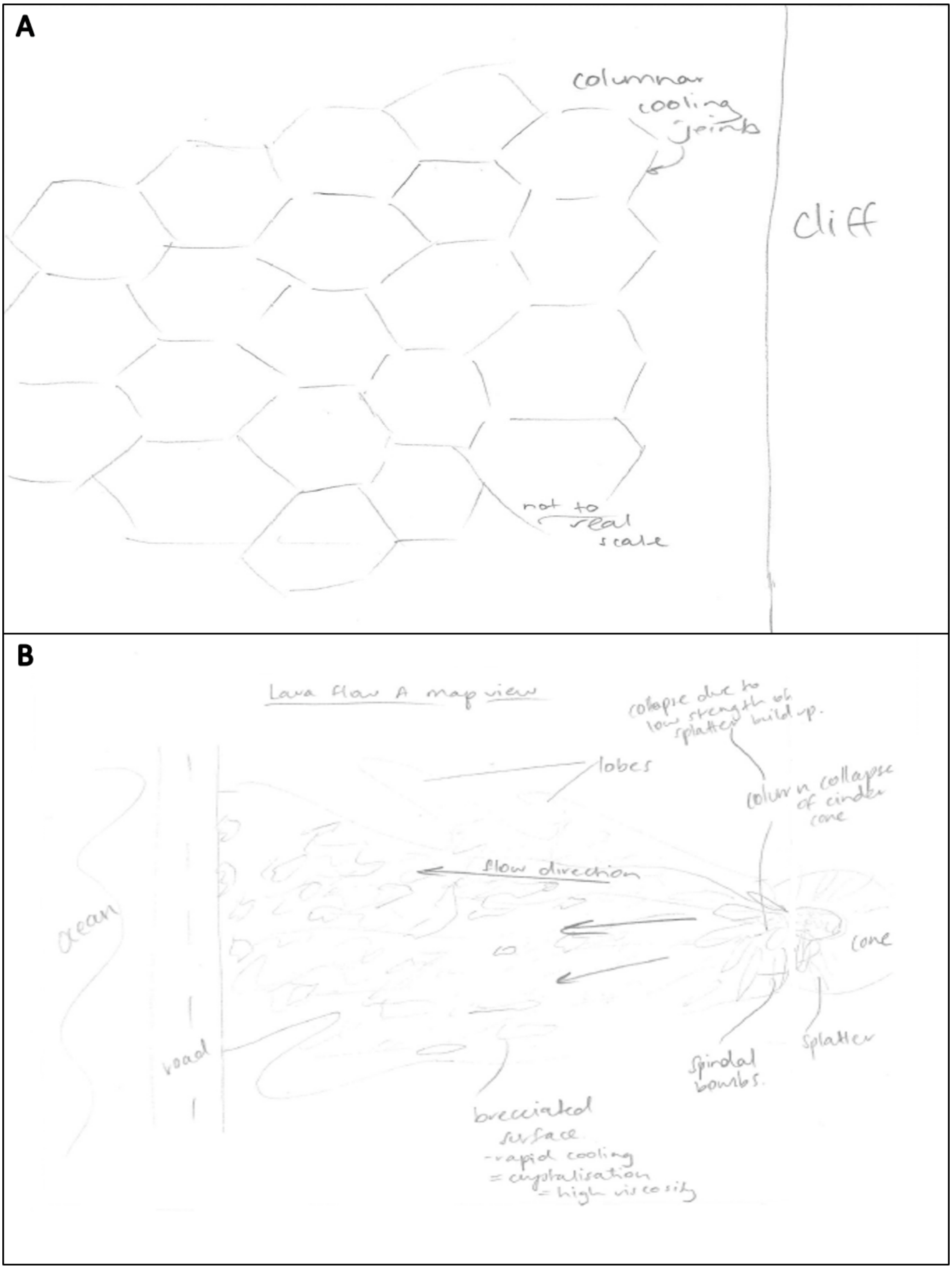

FIGURE 5.2: First and second in-class exercise sketches for Q4. (A) is a student's interpretive sketch in map-view from the first in-class exercise; and (B) is a student's interpretive sketch in map-view from the second in-class exercise

5.3 Important Geological Features to a Volcanologist

The in-class exercise results indicate that the virtual fieldtrip was effective at improving student understanding of the geological features which are important to volcanologists. Throughout the virtual fieldtrip students were exposed to a range of expert volcanologists in the instructional videos.

On average, each student labelled more features in the second in-class exercise (85 features were labelled by students in the first in-class exercise and 115 features were labelled by students in the second in-class exercise). Channels, grain-size and scale were geological features that were only included in student answers within the second in-class exercise. This is important as it shows that the virtual fieldtrip was effective at opening students' eyes to more geological features that are important to volcanologists.

Another interesting point is that thirty-six students answered why the geological features that they labelled were important to a volcanologist in the second in-class exercise (compared to twenty-six students in the first in-class exercise). This shows that students began to understand why these features allowed them to make predictions and interpretations of the Sumner outcrop. The following quotes exemplify this:

"The columnar jointing and brecciation because this shows the features of an a'a' lava flow. The volcanologist would need this information in order to differentiate the type of lava and therefore the eruption style."

"Textures to identify the different types of lava flow; grain-size, thickness of flow, channel type and structure to understand how the lava fluid mechanics worked; grain texture for cooling history and thickness for viscosity/magnitude of erupted lava."

This shows that more students began to categorise and evaluate which geological features (e.g., grain-size, columnar jointing, channels and brecciation) allowed them to determine the cooling rate, lava flow direction, style of eruption and type of lava flow in the Sumner outcrop. This allowed students to make interpretations of the geological history of the Sumner outcrop. This shows that more students progressed to a higher-level of learning (Bloom, 1956) and began to develop geological interpretation skills important in geology (Frodeman, 1995).

5.4 The Dunning-Kruger Effect

People tend to overestimate their abilities in many social and intellectual domains. Kruger and Dunning (1999) suggested that this overestimation occurs partly because unskilled people in the social and intellectual domains make unfortunate choices, and their incompetence robs them of the meta-cognitive ability to realise it. Kruger and Dunning (1999) showed that people who scored in the bottom quartile on a range of tests overestimated their test performance and ability. Studies linked this to deficits in meta-cognitive skills, or the capacity to distinguish accuracy from error (Kruger and Dunning, 1999).

The students who believed that the virtual fieldtrip was most successful at improving sketching and annotation achieved lower learning gains for observational sketching, total interpretive sketching and total annotation, compared to the students who believed the virtual fieldtrip was least successful at improving sketching and annotation. This shows that these students judgement of what they thought improved the most was not a good representation of reality. This is supported by the Dunning-Kruger effect, where the less skilled students overestimated their skills (Kruger and Dunning, 1999). However, these results may be biased due to the low number of students who ranked sketching as the most improved factor following the virtual fieldtrip (n=6 for sketching was the most improved) and annotation as the most improved factor following the virtual fieldtrip (n=4 for annotation was the most improved).

In contrast, the students who believed that the virtual fieldtrip was most successful at improving interpretation (n=27) achieved higher learning gains for total feature interpretation and total interpretive sketching compared to the students who believed the virtual fieldtrip was less successful at improving interpretation. This shows that over half of the students judgement of what they thought improved the most was a good representation of reality. However, these results may be biased due to the low number of students who ranked interpretation as the least improved factor (n=3 for interpretation was the least improved).

5.5 Student Motivation and Effort

Student motivation is part of the affective domain, which also addresses student emotion and regulation of learning. Research on the affective domain of the student experience (e.g., attitudes, emotions, motivation and values) is gaining recognition for its important role in student engagement (Van Der Hoeven Kraft, Srogi, Husman, Semken, and Fuhrman, 2011). Motivation is critical to student learning in any domain including geology (Van Der Hoeven Kraft et al., 2011).

As presented in Chapter 4, students weighted motivation as the equal least successful factor improved following the virtual fieldtrip. However, student answers in the reflective questionnaire indicate that the virtual fieldtrip was enjoyable and fun:

"Was a unique fun way to learn, hasn't been done before with it being interactive as well as a singular exercise. Fun and educational. I've always been quite motivated, but this was great."

Many of these students stated that the 3D visualisations and instructional videos within the virtual fieldtrip made them more motivated. 3D visualisations have been found to develop motivation, interest and attention in students (Dransch, 2000):

"The videos and 3D activities did motivate me to keep working on the correct answers."

The students who believed the virtual fieldtrip was most successful at improving motivation achieved higher learning gains for interpretive sketching and total annotation, compared to the students who believed the virtual fieldtrip was least successful at improving motivation. The students who believed the virtual fieldtrip was least successful at improving motivation achieved higher learning gains for observational sketching and total feature interpretation, relative to the students who believed the virtual fieldtrip was most successful at improving motivation. This signifies that perceived student motivation was not an accurate representation of their learning.

Engagement entails mindfulness, intrinsic motivation, cognitive effort, and attention (Bangert-Drowns and Pyke, 2001; Lee and Anderson, 1993). Kearsley and Shneiderman (1993) also highlight that although engagement can occur without the use of technology, technology offers opportunities for engagement in ways that may otherwise be difficult to achieve. Attributes of engaging student interest include keeping students actively attentive to the content, which allows them to feel they have control over their learning (Van Der Hoeven Kraft et al., 2011). The virtual fieldtrip was inherently an active learning experience, which allowed students to interact with volcanic locations in Iceland. Students reported on the 'interactive' nature of their learning in the virtual fieldtrip. Many students stated that the virtual fieldtrip was an interesting and engaging experience:

"Really interesting topics presented in an engaging + multi-layered way."

The virtual fieldtrip was an engaging experience, which may highlight that the technology utilised in the virtual fieldtrip supported student engagement and motivation.

5.5.1 Effort

Based on the reflective questionnaire results, the majority of students agreed that the virtual fieldtrip improved the effort that they put into sketching the Sumner outcrop. Student answers in the reflective questionnaire stated that the virtual fieldtrip enhanced their ability to understand and interpret lava flows, which resulted in an increase in effort. This is exemplified in the following quote:

"Yes, since I understood how the outcrop formed better (layering, composition etc.). I could write more about the outcrop, describe more processes and annotate better. So yes the amount of effort I put in increased because of the Iceland virtual fieldtrip as I understood more."

However, other students stated that the virtual fieldtrip enhanced their understanding and interpretation of lava flows, but didn't result in an increase in effort:

"I don't think that my amount of effort changed but I believe that the quality of my sketching and interpretation changed to the better after the virtual fieldtrip."

Many of the student answers didn't comment on the effort they put into the Sumner outcrop following the virtual fieldtrip making it difficult to determine if students understood the question:

"It helped me understand the outcrop better as a whole, and therefore I could put more information onto my sketch."

Based on the range of student responses, with many of the responses not explicitly answering the question, it is difficult to determine whether students put more effort into sketching the Sumner outcrop.

5.6 Limitations

The low resolution of the in-class exercise may have influenced the relatively low normalised gains that were observed. According to Hake (1998); gains lower than 0.3 are considered to be in the low region; gains between 0.4 and 0.7 are in the medium region, and gains larger than 0.7 are considered large. Only interpretive sketching in map-view and feature interpretation in map-view achieved medium gains. All other parts scored low-gains. It should be noted that these regions were categorised by Hake (1998) based on the learning over an entire course; whereas, the virtual fieldtrip was an intervention within a course. Because of these low to medium gains, there is ample room for either positive or negative growth.

Another limitation was the low resolution of data in the marking rubric. There was a total of three potential marks (with no partial credit) given for observational sketching, interpretive sketching in side-view, interpretive sketching in map-view and annotated sketch content. These all had a restrictive range, which meant there was a low resolution of data. One way to improve the resolution of the marking rubric would be to increase the point range for each question (or allow half marks to be given). This would result in a greater spread of results. This would make the learning gains more meaningful.

A further limitation was the low sample size for this research (n = 44 for in-class exercise; n=49 for the reflective questionnaire; n=42 for combination of quantitative and qualitative data). Rigorous quantitative research requires larger study populations (or n values) to improve confidence in the validity and reliability of the overall results (Dohaney, 2013). Validating the in-class exercise would also provide more confidence in the results from this study. To validate these results a larger population would be required and more data collection would be useful to better constrain the overall learning gains for the in-class exercise.

The GEOL336 students were taught the material required to complete the in-class exercise in the lava flow module and in the virtual fieldtrip. This occurred within within the same university semester; therefore, an argument can be made that they would perform better in the second in-class exercise, as they had been taught the same material twice and completed the first in-class exercise. However, students usually show a steep decline in retention after the initial learning takes place (Larsen, Butler, and Roediger III, 2009). This means that student retention of the learning which occurred in the lava flow module and was tested in the first in-class exercise likely declined, prior to the learning which occurred in the virtual fieldtrip and was tested in the second in-class exercise.

The effectiveness of Hake's metric may also be suspect as normalised gains are biased towards high pre-test scores, which makes it easier to find statistical significance. The bias inflates differences, which can makes it easier to find statistical significance and can lead to unwarranted claims about course effectiveness (Brogt et al., 2007). Low to medium scores were observed for all parts. There is no bias towards high pre-test scores for these parts based on the low to medium scores. There were high first in-class exercise scores for the observational sketching; however, the observational sketching had low gains, which indicates there was no bias. Overall, Hake's metric was appropriate for this research due to the low test scores.

Chapter 6

Recommendations

In this chapter, the in-class exercise and reflective questionnaire results are used to provide recommendations to improve future iterations of the virtual fieldtrip, and provide a framework for the development of other tertiary geology virtual fieldtrips.

6.1 Logistical Recommendations for the Virtual Fieldtrip

6.1.1 The Flipped Classroom

The flipped classroom utilises video recordings to move traditional lecture-instruction outside of the classroom, and uses face-to-face classroom time for interactive learning and discussion (Missildine, Fountain, Summers, and Gosselin, 2013). In some studies, student engagement in a flipped classroom compared to a traditional classroom have showed that students were more positive about the flipped classroom and developed a better understanding of course content (Missildine et al., 2013). The flipped classroom improves student–student and student–teacher interactions while approaching concepts from different perspectives, therefore resulting in deeper understanding (Bergmann and Sams, 2012).

In-class activities encourage collaboration and teaching among peers, as students acquire knowledge individually before class, both of which are essential to improve knowledge acquisition and student motivation (Bergmann and Sams, 2012). Allowing instructional videos to be watched outside of classroom time allows opportunities for active learning within the classroom to test cognitive skills (Little, 2015). However, despite the advantages of the flipped classroom, some challenges have also been identified. These challenges include an increase in workload relating to content preparation, teacher discomfort with technology and lack of access to technology (Chellapan and van der Meer, 2016).

The Reykjanes location was run within a traditional classroom setting, with students sitting in a row-by-row approach and the lecturer at the front of the classroom. The Heimaey and Krafla locations were completed by most students at home of their own accord. Following the completion of the Heimaey and Krafla locations, students discussed and expanded upon the virtual fieldtrip content within the classroom with their peers and the course lecturer.

The Heimaey and Krafla locations were examples of the flipped classroom in action. The students engaged with the virtual fieldtrip material in between the classroom sessions of their own accord. This allowed the virtual fieldtrip content to be discussed and expanded upon in greater detail within the classroom, which promoted student understanding.

In the future, the flipped classroom will be used for each location in the virtual fieldtrip. Students will be expected to complete and engage in each location of the virtual fieldtrip at home, and then discuss the virtual fieldtrip content within the classroom sessions with their peers and the course instructor. Prior to the start of the virtual fieldtrip, students will be sent an email informing them about the flipped classroom and that it will be used for the virtual fieldtrip. As the completion of the virtual fieldtrip is part of the GEOL336 grade, the students will have a stake in completing the virtual fieldtrip at home.

6.1.2 Learning Space

The design of the classroom space is an important consideration for teaching large classes. In the past, learning spaces have been designed on the traditional row-by-row seating, where a teacher is positioned at the front of the classroom facing the students (Beichner, 2014). In these learning spaces it is difficult to utilise computers, students can't easily share their work with the class and it is more difficult for students to interact with the instructor (Beichner et al., 2007). Teamwork and classroom discussions can be encouraged by providing group learning spaces that can accommodate smaller numbers of students in square tables (Beichner et al., 2007). Tables should be placed so that instructors can freely circulate between them.

The Reykjanes location was run in a traditional classroom 'row-by-row' approach, with limited seating space. This made it difficult for group discussions to take place. Following a discussion between the researcher and the course instructor, it was decided that both the Heimaey and Krafla locations would be run within one of the undergraduate geology laboratories. The geology laboratory space design consists of multiple square tables with chairs positioned around each side (Figure 6.1). This provided more space for students to discuss the material covered in the virtual fieldtrip with their peers and the course instructor. For the next iteration of the virtual fieldtrip, the geology laboratory space will be utilised for all classroom sessions.

FIGURE 6.1: Learning space utilised for the Heimaey and Krafla locations in the virtual fieldtrip

6.2 Recommendations for the GEOL336 Lava Flow Module

One recommendation would be to teach the geological features that were identified in the Sumner outcrop, which were not explicitly taught in the GEOL336 lava flow module. These geological features included solid core, side lobes, toes and sheets. These geological features are important as they align with an intended learning outcome for GEOL336: "discuss physical volcanological processes with relevance to magma properties".

6.3 Pedagogical Recommendations for Content in the Virtual Fieldtrip

One recommendation would be to improve the teaching of the geological features in the virtual fieldtrip that scored low percentages in the second in-class exercise (i.e., the geological features that scored less than fifty percent). This included levees, sheets and channels for annotated geological features; base breccia, scale, flow direction, toe and solid core for feature interpretation in side-view; and vent, scale and channel levee for feature interpretation in map-view. These geological features align with the GEOL336 intended learning outcome: "discuss physical volcanological processes with relevance to magma properties". These geological features are important as they enable students to identify and interpret the geological features and processes that are present in the lava flows in the Sumner outcrop. In the future, these geological features will be included in more photographs within the virtual fieldtrip, and will also be assessed in more of the exercises within the virtual fieldtrip. Other studies have concluded that the reinforcement of lecture content in virtual fieldtrips has a positive effect on student learning and knowledge retention (e.g., Chen et al., 2016; Grechus and Brown, 2000).

Another recommendation would be to specifically teach students to identify ash deposits in the virtual fieldtrip. Ash was the only annotated geological feature taught in the GEOL336 lava flow module and identified in the Sumner outcrop, which was not taught in the virtual fieldtrip. This may have resulted in ash having a lower class percentage in the second in-class exercise, as it wasn't reinforced in the virtual fieldtrip. In the future, a new location will be developed for the virtual fieldtrip (Eyjafjallajökull: the location of the 2012 volcanic eruption in Iceland), which will focus on ash. Ash is a geological feature which aligns with the GEOL336 intended learning outcome: "discuss physical volcanological processes with relevance to magma properties". The importance of ash could be emphasised through reinforcement and application in the virtual fieldtrip.

6.4 Recommendations Based on Student Responses

Question 3 of the reflective questionnaire asked students: *"What aspects of the Iceland virtual fieldtrip could be improved? How could these aspects be improved?"* The aspects of the virtual fieldtrip that students stated could be improved included Padlet, technical difficulties (e.g., slow loading time of the videos and/or the web-page) and the inclusion of a save option.

6.4.1 Padlet

Students stated that it was difficult to type on Padlet, and that Padlet could be improved (39 percent of students):

"Sometimes it was difficult to type on Padlet (lagging a lot), or it wouldn't save what you have written."

There was a consensus amongst these students that it would be better to answer the Padlet questions before being able to see their peers' answers:

"Do not make the answers of the Padlets visible to everyone before answering the questions. Make them visible only after the question has been answered."

To solve this issue, an alternative platform could be implemented. An alternative platform would be the Typeform platform, which was used for one question at the Krafla location in the virtual fieldtrip. Similar to Padlet, the Typeform platform allows users to answer questions on an online discussion board. The main difference is that other students' answers to the original question can only be observed by the student following answer submission. By utilising this platform, students will be able to answer the question based on their own conclusions, while still being able to read other students' answers and receive feedback for their own answer following submission.

6.4.2 Technical Difficulties in the Virtual Fieldtrip

Another aspect of the virtual fieldtrip that students thought could be improved was to fix any technical difficulties (20 percent of students). These technical difficulties included the slow loading time of the videos and the web-page:

"The only problems that I experienced were technical difficulties. Some videos didn't load (the 360 videos) and it took a long time to fix."

"Sometimes the website was slow, I don't know if this can be improved as it may be due to the amount of people online."

To negate these technical difficulties, students could complete the virtual fieldtrip at home. A number of students found that the web-page was quicker while completing the virtual fieldtrip on their own laptops at home. The downside to this approach would be if students did not complete the virtual fieldtrip at home. However, as the completion of the virtual fieldtrip is worth part of the GEOL336 grade, students have a stake in completing the virtual fieldtrip at home.

6.4.3 Save Option

14 percent of students stated that including a save option to the website would improve the virtual fieldtrip:

"Most recommended: logging in or having your own profile and ability to save answers that you created along the way. This would eliminate the need for PDF submission."

To remediate this, in the next iteration of the virtual fieldtrip students will be able to save their work following the completion of each exercise in the virtual fieldtrip. The multiple-choice question and discussion board answers will be saved to the same computer using cookies. Following the completion of each location in the virtual fieldtrip, students will be redirected to a spreadsheet containing all of their answers before they submit. This will allow students to save and continue at any point within the virtual fieldtrip.

6.5 Recommendations for Sketching in the Virtual Fieldtrip

Student's stated in Q3 of the reflective questionnaire that one way to improve the virtual fieldtrip would be to include sketching exercises in the virtual fieldtrip:

"I think that there should be sections where you can practice sketching the outcrop – want help with sketching."

Although students achieved positive learning gains for interpretive sketching in side-view and map-view, there was still ample room for growth (or decay). In other studies, multiple sketching activities have been incorporated in virtual field environments to facilitate improvements in visual-spatial reasoning (Dolphin et al., 2019). The intent of sketching in these environments was to encourage students to start separating useful data from 'noise' in a virtual field setting, which would be a first step in introducing students to the hermeneutic process of geology (Frodeman, 1995).

A potential option to further improve student interpretive sketching would be to implement predictive sketching in the virtual fieldtrip. Predictive sketching is the use of sketching to make a prediction (Ormand et al., 2017). For example, a student can be asked to predict what a cross-section through a photograph of a geological structure will look like. Predictive sketching, combined with immediate feedback on sketch accuracy, can be a powerful tool for learning (Gagnier et al., 2017).

Predictive sketching exercises of lava flows will be incorporated in the next iteration of the virtual fieldtrip. Students will have the opportunity to either complete these predictive sketches on paper and photocopy them, or complete the sketches using MS Paint. The sketches will then be uploaded to the virtual fieldtrip. As predictive sketching requires students to make an immediate comparison to the correct answer. The correct predictive sketch will be supplied as feedback in the virtual fieldtrip. This will allow students to evaluate their own sketches for accuracy using the feedback (Ormand et al., 2017).

6.6 Framework for Tertiary Geology Virtual Fieldtrips

Based on Jolley et al. (2018) there are four critical elements for successful virtual fieldtrips: 1) constructively aligned content; 2) assessment opportunities; 3) student experience; and 4) connection to place and people. These elements are expanded upon below, with the addition of some new critical elements.

The intended learning outcomes for a virtual fieldtrip need to be aligned with the intended learning outcomes for the course. This is to ensure that the intended learning outcomes for the virtual fieldtrip are well developed, and that they match the course curriculum content and assessment. The reinforcement of course content within a virtual fieldtrip is successful at aiding student learning and knowledge retention.

Assessment opportunities such as multiple-choice questions and discussion boards should be provided throughout a virtual fieldtrip. Assessment can be designed to scaffold students from a lower-level of learning to a higher-level of learning. Assessment opportunities should include some for practice and feedback (formative), and some for marks (summative) (Jolley et al., 2018). Instantaneous feedback should also be provided following assessment.

Opportunities for reflection should also be provided throughout a virtual fieldtrip (e.g., classroom discussions) or on completion of a virtual fieldtrip (e.g., reflective questionnaires). This allows students to reflect on the virtual fieldtrip experience and the learning in the virtual fieldtrip.

3D visualisations and instructional videos are useful tools to deliver the required information to successfully complete activities within a virtual fieldtrip and achieve the intended learning outcomes. The inclusion of 3D visualisations and instructional videos in virtual fieldtrips aids the development of higher-level learning such as interpretation, and allows students to spatially explore geological models. These technologies can also enhance student motivation and engage student interest.

Students must feel connected to a virtual fieldtrip experience. This can be achieved by filming the course instructor in instructional videos. The course instructor can take ownership of a virtual fieldtrip and became a student guide (Jolley et al., 2018).

Virtual fieldtrip pedagogy must act to develop a sense of place in students (Jolley et al., 2018). Google Maps and Google Earth can be used to help students build their own sense of place by allowing them to explore the landscape. A virtual 'fly-over' to given locations in a virtual fieldtrip can be used to give students the sense of travelling to a field location.

Implementing the flipped classroom provides students with the opportunity to complete the activities within a virtual fieldtrip outside of the classroom, which allows time for discussion in the classroom. This allows students to discuss the content in greater detail with the course instructor. The learning space where students participate in classroom discussion should facilitate student-student and student-instructor discussion.

Asynchronous virtual fieldtrips allow for future development based on student feedback. This can minimise technical hitches and lecturer stress; while also creating opportunities to improve and adjust virtual fieldtrip content and delivery.

Chapter 7

Conclusions

A review of the relevant literature showed that virtual fieldtrips have been developed to both augment and in some cases replace geological fieldwork. However, little research has established the effectiveness of virtual fieldtrips at aiding the development of geological skills (e.g., sketching and interpretation) and the learning gains measured as a result of virtual fieldtrips. This research aimed to determine the effectiveness of the virtual fieldtrip to aid sketching and interpretation of lava flows, through the analysis of the in-class exercise and reflective questionnaire results. This research also aimed to provide recommendations for future iterations of the virtual fieldtrip, and develop a framework for tertiary geology virtual fieldtrips.

The analysis of the in-class exercise results indicate that:

- The virtual fieldtrip was effective at aiding observational sketching and annotation (sketch and geological content) of the Sumner outcrop (lower-level learning skills).
- The virtual fieldtrip was more effective at developing skills that required higher-level thinking (e.g., interpretative sketching and feature interpretation) than those that required lower-level thinking (e.g., observational sketching and annotation (sketch and geological content)).
- Students included more geological features and processes in the second in-class exercise. This indicates that the reinforcement of geological features and processes in the virtual fieldtrip was beneficial at aiding student sketching and interpretation of lava flows.
- Students listed more geological features as important to a volcanologist in the second in-class exercise and provided more reasons as to why these features were important to a volcanologist. This indicates that students progressed to a higher-level of learning following the virtual fieldtrip.

The analysis of the reflective questionnaire results indicate that:

- Students weighted the virtual fieldtrip as being most successful at aiding their interpretation in the in-class exercise. This agreed with the higher learning gains for interpretation, indicating that students realised what the virtual fieldtrip was most successful at improving.
- Students stated that the instructional videos and 3D visualisations in the virtual fieldtrip allowed them to interact with the environment, and that they aided their interpretation of the Sumner outcrop in the in-class exercise.
- Students generally found the virtual fieldtrip an enjoyable, interesting and motivating experience. Some students said influenced their effort in the in-class exercise.

The recommendations for future iterations of the virtual fieldtrip include: 1) implementing the flipped classroom; 2) providing learning spaces that encourage classroom discussion; 3) streamlining content taught in both the GEOL336 lava flow module and the virtual fieldtrip; 4) fixing technical difficulties in the virtual fieldtrip; 5) including a save option for the virtual fieldtrip; and 6) introducing predictive sketching in the virtual fieldtrip.

The framework for tertiary geology virtual fieldtrips includes: 1) constructively aligning content; 2) providing a range of formative and summative assessment opportunities; 3) providing opportunities for reflection; 4) implementing appropriate technologies to deliver content (e.g., 3D visualisations and instructional videos); 5) connecting students to the virtual fieldtrip experience; and 6) using a learning space which encourages group discussion.

Summary

Based on the results, the virtual fieldtrip was an effective tool to aid student sketching and interpretation of lava flows. The in-class exercise and reflective questionnaire were successful at measuring the learning which occurred in the virtual fieldtrip. This research has contributed to the literature by measuring the learning gains that occur as a result of virtual fieldtrips, and it showed that the development of geological skills such as sketching and interpretation can be aided using virtual fieldtrips.

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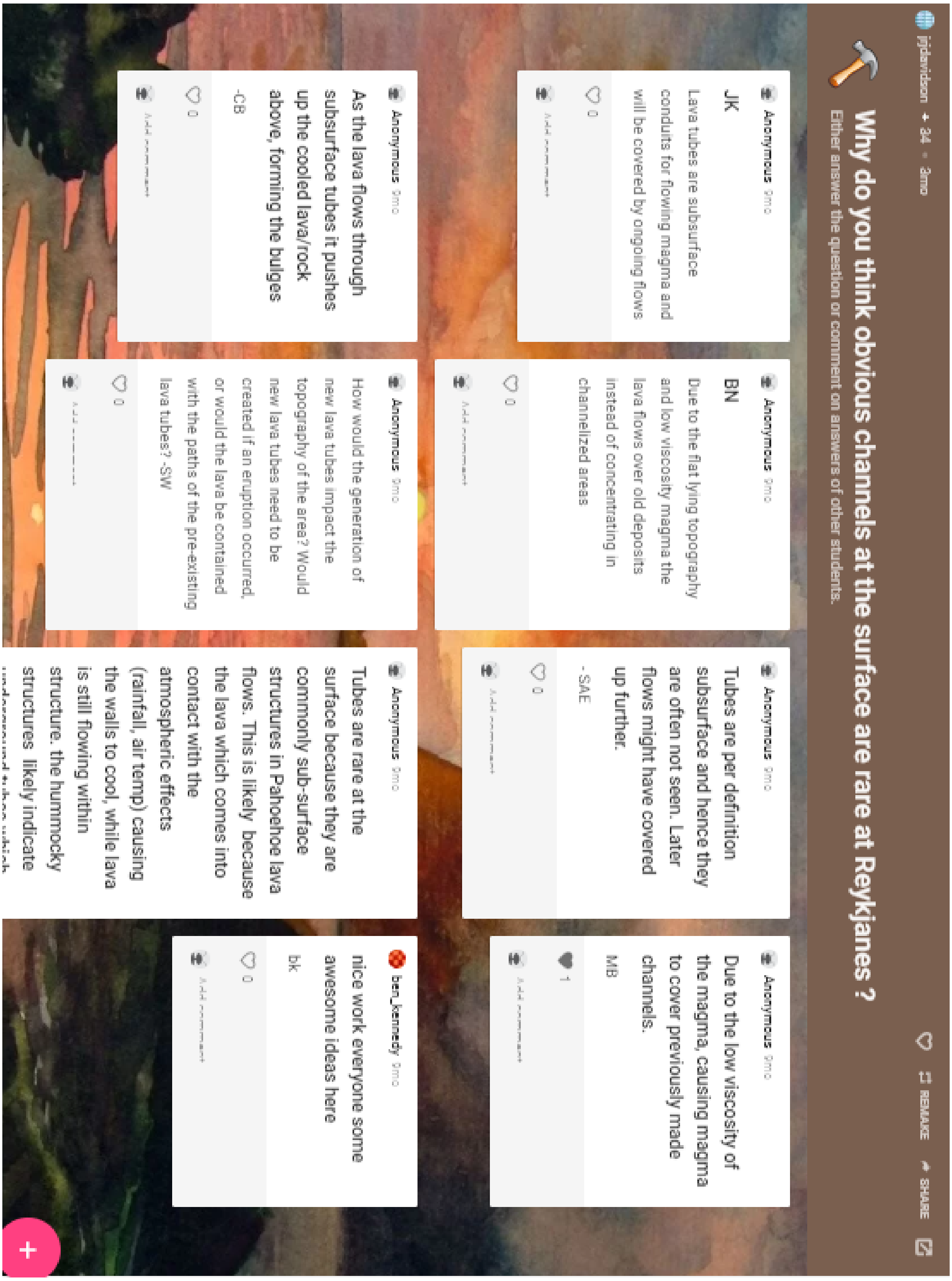
Appendix A

Padlet Layout


jrjdavidson • 34 • 3mo
Why do you think obvious channels at the surface are rare at Reykjanes ?
Either answer the question or comment on answers of other students.
REMAKE
SHARE
Anonymous 3mo
JK
Lava tubes are subsurface conduits for flowing magma and will be covered by ongoing flows
0
Add comment
Anonymous 3mo
BN
Due to the flat lying topography and low viscosity magma the lava flows over old deposits instead of concentrating in channelized areas
0
Add comment
Anonymous 3mo
Tubes are per definition subsurface and hence they are often not seen. Later flows might have covered up further.
- SAE
0
Add comment
Anonymous 3mo
Due to the low viscosity of the magma, causing magma to cover previously made channels.
MB
1
Add comment
Anonymous 3mo
As the lava flows through subsurface tubes it pushes up the cooled lava/rock above, forming the bulges
-CB
0
Add comment
Anonymous 3mo
How would the generation of new lava tubes impact the topography of the area? Would new lava tubes need to be created if an eruption occurred, or would the lava be contained with the paths of the pre-existing lava tubes? -SW
0
Add comment
Anonymous 3mo
Tubes are rare at the surface because they are commonly sub-surface structures in Pahoehoe lava flows. This is likely because the lava which comes into contact with the atmospheric effects (rainfall, air temp) causing the walls to cool, while lava is still flowing within structure. the hummocky structures likely indicate
ben_kennedy 3mo
nice work everyone some awesome ideas here
bk
0
Add comment

Appendix B

In-Class Exercise

1. Sketch and annotate the key geological features of this outcrop.

2. Which of the labels in your sketch are most important to a volcanologist? Why?

3. Produce an interpretive sketch of lava flow A in cross-section, perpendicular to the cliff face (side-view) and annotate the key geologic features and processes that you might expect from this perspective.

4. Produce an interpretive sketch of lava flow A in map view (birds-eye view) and annotate the key geological features and processes that you might expect from this perspective.

Appendix C

In-Class Exercise Marking Rubric

	1	2	3	4
Observational Sketch /3	No sketch attempted (0 pts)	Sketch lacks detail or is illegible and difficult to interpret (1 pts)	Sketch lacks some detail or not clearly drawn or labelled (2 pts)	Sketch detailed, clearly drawn and annotated (3 pts)
Annotated Sketch Content /3	No key sketch features labelled (0 pts)	Essential sketch features not labelled (1 pts)	Most sketch features labelled (2 pts)	All sketch features labelled (3 pts)
Annotated Geological Content /10	No key geological features sketched, annotated or described (0 pts)	Essential geological features not sketched, annotated or described (1-4 pts)	Most geological features are sketched, annotated or described (5-7 pts)	All essential geological features are sketched annotated or described (8-10 pts)

Rubric for Q1: Sketch and annotate the key geological features of this outcrop

Total: /16

	1	2	3	4
Interpretive sketch in side-view /3	No sketch attempted (0 pts)	Sketch lacks detail or is illegible and difficult to interpret (1 pts)	Sketch lacks some detail or not clearly drawn or labelled (2 pts)	Sketch detailed, clearly drawn and annotated (3 pts)
Geological feature interpretation in side-view /8	No key geological features sketched, annotated or described (0 pts)	Essential geological features not sketched, annotated or described (1-3 pts)	Most geological features are sketched, annotated or described (4-6 pts)	All essential geological features are sketched annotated or described (7-8 pts)

Rubric for Q3: Produce an interpretative sketch of lava flow A in cross-section, perpendicular to the cliff face and annotate the key geologic features and processes that you might expect from this perspective

Total /11

	1	2	3	4
Interpretive sketch in map-view /3	No Sketch Attempted (0 pts)	Sketch lacks detail or is illegible and difficult to interpret (1 pts)	Sketch lacks some detail or not clearly drawn or labelled (2 pts)	Sketch detailed, clearly drawn and annotated (3 pts)
Geological feature interpretation in map-view /8	No key geological features sketched, annotated or described (0 pts)	Essential geological features not sketched, annotated or described (1-3 pts)	Most geological features are sketched, annotated or described (4-6 pts)	All essential geological features are sketched annotated or described (7-8 pts)

Rubric for Q4: Produce an interpretative sketch of lava flow A in map view (birds-eye view) and annotate the key geological features and processes that you might expect from this perspective.

Total /11

Annotated sketch content (Q1) -Other feature sketched (e.g. plants, rock bund) -Direction arrow -Appropriate Scale	**Annotated geological content (Q1)** -Multiple layers -Lava flows and lava type -Ash layer -Distinct channel -Distinct sheet -Colours -Columnar joints or cooling joints -Upper breccia -Lower breccia -Levees -Other geological features (up to 3 features)
Geological Feature Interpretation in Side-View (Q3) -Flow direction or vent location -Top breccia -Base breccia -Solid core -Columnar joints or cooling joints -Outburst toe or a’a’ toe -Scale -Other geological features (up to 3 features)	**Geological Feature Interpretation in Map-View (Q4)** -Deep channel levee -Channel constrained -Front breccia or toe -Flow direction -Vent or source location -Side lobes -Scale -Other geological features (up to 3 features)

Appendix D

Reflective Questionnaire

1. What aspects of the Iceland virtual fieldtrip helped you with your interpretation of the outcrop at Sumner? Why?

2. How successful was the Iceland virtual fieldtrip at improving the following? Weight these adding up to 100% and explain your reasoning. Sketching, annotation, motivation and interpretation E.g. (sketching: 75; annotation: 10; motivation: 5; interpretation: 10).

3. What aspects of the Iceland virtual fieldtrip could be improved? How could these aspects be improved?

4. Do you think that the Iceland virtual fieldtrip influenced the amount of effort you put into sketching the lava outcrop. (Circle one) Explain your answer. 1) Strongly disagree 2) Disagree 3) Neutral 4) Agree 5) Strongly agree